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Japan Report

(FOUO 25/82)

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CONTENTS

MILITARY

RECENT DEFENSE-RELATED INDUSTRY ACTIVITIES REPORTED

Engine for MTX

Tokyo NIKKEI SANGYO SHIMBUN in Japanese 22 Jan 82 p 9

[Text] Ishikawajima-Harima Heavy Industries has recently delivered to the Defense Agency the first and second prototype F3 engines to be mounted in the MTX. The Defense Agency appropriated approximately 9 billion yen in FY-80 and FY-81 for development of this engine by Ishikawajima-Harima. After testing, the Defense Agency will examine and compare its price and performance to that of candidate engines from Garrett of the United States and Snecma of France. By this October, a final decision is expected to be made on whether or not the F3 engine will be used in the MTX.

MTX development was begun last fall by Kawasaki Heavy Industries as the main contractor. It is the earnest wish of both the Defense Agency and the industry that a fuselage as well as an engine be developed in Japan. Concerning the F3 engine, five prototypes were ordered from Ishikawajima-Harima during FY-80, 1 year before the fuselage. Furthermore, four additional prototypes are to be ordered by the end of FY-81.

Ishikawajima-Harima has delivered two out of five prototype engines ordered in FY-80. By this summer it expects to deliver the remaining three engines. These prototype engines already fulfill the performance requirement of generating 1.6 tons of thrust. The Defense Agency is planning to conduct tests in high-altitude experiment facilities in the United States where humidity and atmospheric pressure are adjusted to simulate actual flying conditions in July through September. In the meantime, it is also planning to conduct various performance tests within Japan by mounting F3 engines in a modified C1 transport plane.

Examining the results of these tests, the Defense Agency is supposed to make a final decision on whether or not the F3 engine will be used for the MTX in October. Because Garrett and Snecma are also in the process of developing engines of this class as a derivative of other engine types, it is expected that the F3 engine will be chosen if its cost can meet the target of 100-150 million yen apiece in 1980 prices.

The development of the MTX is expected to be completed by FY-87. The Air Self Defense Force plans to order about 200 MTX's. Since two engines are mounted in each MTX, the total number of engines ordered will be about

500 including spares. If the F3 engine is chosen, as of FY-83 the contractor is supposed to start manufacturing engines which will actually be mounted on the MTX on a trial basis.

Model 88 Tank

Tokyo NIKKEI SANGYO SHIMBUN in Japanese 6 Feb 82 p 6

[Text] The Defense Agency will start basic design work and manufacture of prototypes for parts such as the turret in order to develop a new tank that will succeed the model 74 tank as of FY-82. The Defense Agency has formulated a 3-year plan to produce a first-phase prototype of a new tank starting in FY-82, and a partial budget was appropriated for items such as basic design in the government's budget draft for FY-82. Since a new tank is targeted for a final decision (on development) in 1988, the new tank is called the model 88 tank. It will be developed by Mitsubishi Heavy Industries as the main contractor. The turret will be developed by Japan Steel Works, Ltd. The technical development headquarters of these corporations and the Defense Agency have been making prototypes of parts such as the engine one by one. This stage of research and prototype parts production was completed at the end of FY-81. Therefore, they will start a substantial portion of the development of the new tank as of FY-82. They intend to develop a tank of the world's highest standards by improving the firepower and mobility.

According to the Defense Agency's development plan, the first phase prototype of the tank will be completed in FY-82 through FY-84 and the second-phase prototype in FY-85 and FY-86. Then, the Defense Agency will conduct practical application tests and decide formally to deploy it in units in 1988. Although the Defense Agency requested approximately 7 billion yen as development expenses for an entire first-phase prototype, only approximately 1.3 billion yen (for the 2 years FY-82 and FY-83) was approved in the government' budget draft as expenses for basic design of the entire tank and for production of prototypes of some parts such as the turret. The Defense Agency, however, hopes to proceed with the development plan as originally scheduled by requesting additional appropriations in the budgets after FY-83.

The outline of the model 88 tank will be determined in consideration of a balance between firepower, mobility, and protectability. As for firepower, the 105 mm turret of the model 74 tank will be replaced with a 120 mm turret. As for the engine to be mounted, the agency is planning to use a 10-cylinder water cooled engine with 1,500 horsepower, which is almost twice as powerful as the engine of the model 74 tank. An increase in running speed and application of compound bulletproof structures are also subjects of study. The number of crewmen will be reduced from the four in the model 74 tank to three.

The Defense Agency has been producing prototypes parts by contracting with Mitsubishi Heavy Industries for bodies and engines and with Japan Steel Works for turrets. It will bring these prototype parts together to assemble a tank as of FY-82. The prototype turret, for which prototype production has been provided in the FY-82 budget, is supposed to be designed so that ammunition will be interchangeable with that of U.S. forces.

Mitsubishi Heavy Industries, the main contractor, is seriously preparing for development of the model 88 tank in hopes of increasing fuel efficiency by improving engine performance and reducing total weight, while trying to make various apparatuses work efficiently by applying mechatronics technology.

Because the budget for the entire first-phase prototype was not approved in the government's budget draft, there are some areas where Mitsubishi Heavy Industries has to invest in advance. Therefore, it plans to work out the details with the Defense Agency in the near future.

Mitsubishi To Remodel F-4

Tokyo NIKKAN KOGYO SHIMBUN in Japanese 25 Feb 82 p 11

[Text] The Defense Agency has decided to sign a contract with Mitsubishi Heavy Industries (Soichiro Suenaga, president) in March for a portion of the service life prolongation plan (ASIP) of the trial remodeling project of the F-4 Phantom (EJ) fighter-interceptor aircraft, which has been an object of dispute in the Diet. Because the execution of the FY-81 budget has been suspended for the capability improvement portion of the plan, the Defense Agency and Mitsubishi Heavy Industries will sign a contract only for the service life prolongation portion of the plan. Immediately after signing the contract, Mitsubishi Heavy Industries will purchase 25 VGH (velocity, gravity, and height) data recorders with the budgeted 700 million yen. Then, it plans to extend the present 3,000-hour (hours in the air) lifespan of the F-4 by about 2,000 hours to make a 5,000-hour lifespan. The ASIP requires that records of actual use of each F-4 compiled by a load frequency meter and information from a VGH data recorder be processed by computer. After examining the degree of wear and the limits of each aircraft, the agency will formulate a remodeling plan. As for the capability improvement plan, as soon as the suspension of the budget is removed, the Defense Agency hopes to select a contractor quickly.

Mitsubishi Heavy Industries started licensed production of the F-4EJ in 1970. It manufactured a total of 140 F-4EJ's by May 1981, when it delivered the last aircraft to the Defense Agency. Other aircraft manufacturers are Kawasaki Heavy Industries and Fuji Heavy Industries. However, in the case of the ASIP for the F-4, Mitsubishi Heavy Industries was chosen as contractor because of its past experience of dealing with F-4's.

According to the ASIP, a VGH data recorder, which analyzes the aircraft body's degree of safety, will be installed in one of every six of the 132 F-4EJ's currently held by the Defense Agency. Then, information from VGH data recorders will be processed by computer along with records of actual use (C/A data) compiled by load frequency meters installed in every F-4EJ. From the computer, (1) the present condition and future prospect of wear in each aircraft and (2) limits of wear of related structural parts will be obtained in order to gather basic materials for checkups and repairs. The Defense Agency is studying the possibility of domestically producing a part of the software needed for computer processing. Mitsubishi Electric Co and Tokyo Precision Instrument Co are under consideration as possible contractors. The software will be prepared from FY-81 through FY-83. Employment of the ASIP will begin after the completion of software preparation in FY-84.

The lifespan of an aircraft used to be determined as the time when a representative aircraft of the type was wrecked. Owing to the progress of nondestructive and other testing technologies, however, it has become possible to determine the lifespan of individual aircraft. The conception of an ASIP was originally formulated in the United States in 1972, and it was first applied to the F-4E. The Air Self Defense Force sent a study team to the United States in FY-80 to see whether or not supply of the ASIP software by the United States was possible.

In the case of aircraft, load is imposed on wing joints and outside shell plates, and these parts wear. The ASIP is intended to find worn parts and replace them with new parts. According to the Defense Agency, although the degree of wear differs in each aircraft, the plan is to extend the life of aircraft from the present 3,000 hours to 5,000 hours.

The ASIP and capability improvement are two sides of the F-4EJ trial remodeling project. The capability improvement plan includes replacement of the U.S. Westinghouse APQ 120 fire control system with the Westinghouse APG 66, which has been installed in the small F-16 fighters, and installation of a new central computer (made by IBM of the United States), which has been installed in F-15's. As the result, the missiles carried by the aircraft will be the most advanced AIM-7F's and AIM-9L's. In addition, the remodeled F-4EJ's will carry anti-ship air-to-surface missiles and posses a bombing capability. The execution of the budget has been suspended for the capability improvement plan due to a dispute in the Diet over Mr Masuda's (former director general of the Defense Agency) statement in 1968 that "Fighter aircraft should not be equipped with bombing capabilities."

Judging that the suspension on the expenditure of 1.3 billion yen for design costs will be removed soon, the Defense Agency hopes to hasten selection of a contractor. Although Mitsubishi Heavy Industries is most likely to get a contract for the capability improvement plan as in the case of the ASIP, the company appears to need technical assistance from electrical manufacturers in the fields of fire control systems, central computers, headup displays, and inertial navigation systems.

Optical Communications Military Applications

Tokyo DENPA SHIMBUN in Japanese 27 Feb 82 p 2

[Text] According to information revealed by a concerned source on 26 February, Mitsubishi Heavy Industries and Mitsubishi Electric Company, the largest defense contractor and the defense contractor ranking high in the amount of orders received, respectively, have started to develop optical communications systems for military uses in order to prepare for the application of optical communications to information processing in fighter aircraft and warships of the Self Defense Forces.

Due to a sharp increase in computers and electronic apparatuses installed in fighters and warships, all wiring requirements cannot be handled by the presently used copper cables. Therefore, they have decided to hasten research and development of optical communications systems for military applications.

On the other hand, the First Research Laboratory of the Technical Research Headquarters of the Defense Agency has been studying military applications of optical communications together with manufactuers of optical communications-related apparatus.

For this reason, military uses of highly advanced optical communications technologies, such as the high-speed digital communications that have been developing rapidly in nondefense sectors, are expected to progress at a rapid pace hereafter.

According to the source, Mitsubishi Heavy Industries and Mitsubishi Electric have formed an engineer-level committee which has been studying military applications of optical communications. They are trying to build up a system within a short time in order to be able to respond at any time if the Self Defense Forces decide to use optical communications systems for information processing in fighters and warships.

Various electronic apparatuses such as central computers, inertial navigation systems, and fire control systems have been installed in the newest fighters and warships. Thus, they have become, so to speak, "a mass of electronic apparatuses." Accompanying this tendency, the volume of internal information has grown enormously and cannot be handled by copper cables any more. This is why the two companies have started serious study of military applications of optical communications.

If optical communication systems are used, data communications can be increased in volume and concurrently reduced in weight. In addition, there are merits such as elimination of electromagnetic waves and facilitation of highly dense wiring.

Fighters and other military aircraft have, among other things, been highly computerized. The size of missile control and other fire control devices and inertial navigation equipment has become very small. Instrument panels in front of the pilot's seat have been in a process of digitalization.

Within the limited space of an aircraft, communications circuits connecting these electronic apparatuses are bulky as well as heavy. Consequently, the future use of optical communications is inevitable in fighters. The United States has also begun experiments to apply optical communications in fighters.

For this reason, on the assumption that "the age of optical communications" for fighters and warships will come in Japan, both companies have begun serious study of systems development and related parts usable in military applications such as optical cables, light-emitting elements, and optical connectors, and the checking of their durability and reliability.

Until now, the only instance of military application of optical communications in Japan has been the use of a very short optical fiber as part of the radar equipment. However, if plans for a ground support fighter (FSX) to replace the F-4 Phantom, which will be greatly reshaped by installation of the most advanced electronic apparatuses and plans for an improved mobility aircraft (CCV), which is under development as a fighter of the future, are realized, large-scale application of optical communications can be foreseen.

Domestic Missile Development

Tokyo NIHON KEIZAI SHIMBUN in Japanse 1 Mar 82 p 10

[Text] The Defense Agency and defense equipment manufacturers have been actively engaged in development of missiles. As of FY-82 the Defense Agency will start development of an anti-ship surface-to-surface missile (Mitsubishi Heavy Industries in charge) and a middle-range anti-tank missile (Kawasaki Heavy Industries and Nippon Electric Company in charge). In addition, Mitsubishi Heavy Industries has started research and development of an air-to-air missile commissioned by the Defense Agency. Tokyo Shibaura Electric Company also started development of a hand-carried SAM (surface-to-air missile). Domestic missile development projects are jostling with one another. All of them are intended to be employed after 1985. If the Defense Agency formally decides to employ them, several tens of billions of yen in orders are expected. Consequently, the manufacturers developing them are highly motivated. Because electronic technologies for nondefense use can be applied to guidance equipment and other components, missiles and considered "a weapon suitable for Japan." For this reason, they seem to be the core of defense equipment development.

Makers Expect To Receive Several Tens of Billions of Yen in Orders

The anti-ship surface-to-surface missile which will formally become a Defense Agency development project as of FY-82 is a missile to attack from land enemy ships which try to reach the shore. Based on the technology used to develop the ASM-1--an anti-ship air-to-surface missile--Mitsubishi Heavy Industries is planning to develop an anti-ship surface-to-surface missile. It expects to complete development by FY-87.

The middle-range anti-tank missile is for attacking tanks. One of its characteristics is the application of a new system whereby a missile radiates laser beams toward enemy tanks and chases the reflected light. Kawasaki Heavy Industries, the main contractor, and Nippon Electric Company in charge of guidance equipment, have been making components on a trial basis and advancing the research and development prior to the formal inauguration of the Defense Agency's development plan. They expect to complete development in FY-86.

The air-to-air missile (AAM for aèrial dogfights) that Mitsubishi Heavy Industries plans to develop is intended to succeed the AIM-9L Sidewinder, which is to be manufactured under license from a U.S. company. The hand-carried SAM that Toshiba has been developing is also intended to be a future replacement for one currently imported by the Defense Agency. Toshiba is planning to apply a CCD (charge-coupled device) used for home VTR cameras in the homing device which locks onto enemy fighters. The plan has attracted a great deal of attention from the technological viewpoint.

For the development of defense equipment such as missiles, the Defense Agency ordinarily appropriates a development budget and commissions companies to do the work. However, the Defense Agency will conduct its own research on the development of the Nike Phoenix, a possible replacement for Nike and Hawk surface-to-air missiles. The Defense Agency is also positively studying the components necessary to improve the performance of missiles. The Defense Agency has commissioned Fujitsu to develop an IR (infrared) CCD that will possess the capability to detect infrared rays.

Japanese missile production has mainly been production under license from U.S. companies, as in the case of the Nike and Hawk. However, with the successful development of Mitsubishi Heavy Industries' ASM 1 and Toshiba's short-range SAM (short-range surface-to-air missile) and the beginning of their installation, domestic missile development has gained momentum.

Development of F-1's Successor

Tokyo NIKKAN KOGYO SHIMBUN in Japanese 2 Mar 82 p 9

[Text] The idea of developing a successor to the F-1 support fighter (FSX) has been quickly boiled down to the essentials, and the Defense Agency has decided to launch the development plan for the post F-1 aircraft as "research and development for future fighters" in the FY-81 Mid-Term Operations Estimate which the Defense Agency has been hastening to draft. Mitsubishi Heavy Industries, Japan's only fighter airplane manufacturer, is eager to develop the aircraft, saying "we want to make an FSX that can engage in a high-level air battle after firing anti-ship missiles and dropping bombs" (Kenji Ikeda, managing director of Mitsubishi Heavy Industries). The Defense Agency seems to be thinking of approximately 200 billion yen for research and development expenses. While preparing three flying corps of support fighters (F-1), the Defense Agency is attempting to increase support capability by prolonging the service life and improving capability (trial remodeling) of the F-4 (EJ) which soon will exhaust their flying hours. One hundred out of the 132 F-4 fighters the Air Self Defense Force now possesses will be remodeled. The competition in terms of military uses between the FSX and the remodeled F-4 as a successor to the F-1, whose manufacture is supposedly to cease soon, has begun to attract attention.

Support fighters are loaded with a large number of anti-ship air-to-surface missiles and bombs. They assume the mission of aerial attack against enemy ships which threaten the sea lanes and fleets which try to land troops and preventing enemy invasion by attacking at the water's edge. The FSX is intended for development as a successor to the F-1. FSX fighters are supposed to possess the capability not only for support at sea but also to attack tanks and supply bases of enemies which have landed. On the ocean, an ordinary pulse radar can pick up targets such as warships. But that is not the case on land. The FSX is expected to add the ground support capability that the F-1 lacks by using a pulse doppler radar to improve look-down capability and, furthermore, by installing a laser precision targeting system.

Research and development of the FSX will start in the latter half of the FY-81 Mid-Term Operations Estimate (FY 83-87). Development expenses are estimated to be approximately 200 billion yen. The 8.5 billion yen appropriated as expenses for trail remodeling of the F-4 in the FY-82 budget is extremely small in terms of cost compared with the case of developing an aircraft in the United States. Since the remodeled F-4 will be equipped with apparatuses from the world's most advanced ground attack airplanes and support fighters, the remodeling of the F-4 may look like an experiment for the FSX. Because the F-4 is an excellent fighter-inspector and can take off and land on an aircraft carrier, the F-4 is expected to be remodeled into a support fighter with extraordinary capabilities.

In remodeling the F-4, the Westinghouse APQ 120 will be replaced by the digital APG 66 (Westinghouse) as an FCS radar. An APG 66 is the FCS radar installed in the F-16 and has a history of being a target for worldwide condemnation because it was used in the Israeli attack on the Iraqi nuclear power reactor. As for a radar display, the 29200-01 by Kaiser of the United States, which is also the F-16's radar display, will be installed. As for a central computer, IBM's CP 1075/AYK, which has already been released for the F-15, will be used. As for an inertial navigation system which flies an aircraft to a destination without guidance, the LL 39 (made by Litton) which is used in the A-10, America's representative tank attack airplane, will be installed. Since the F-4 will be equipped with all these apparatuses, remodeling of each aircraft will cost 8.5 billion yen. As Mitsubishi Heavy Industries will receive the contract for remodeling the F-4, it is expected to accumulate knowhow concerning ground support capabilities and should be able to apply a considerable portion of this knowledge to the FSX.

If all 100 modifiable F-4's are converted to remodeled F-4's, the Defense Agency may face a decision as to whether the remodeled F-4's will be used as fighter-interceptors or ground support fighters. According to the national defense plan outline, the number of fighter-interceptors has been set at about 250. The plans for additional purchases of F-15's and remodeling of the F-4's happen to coincide. But the F-15's cost over 10 billion yen apiece, and under the present difficult financial conditions the additional purchase of F-15's is difficult. For this reason, it is possible to cancel some of the items in the mass production stage of F-4 remodeling and to make remodeled F-4's fighter-interceptors. In this scenario, the necessity of the FSX is increased.

Value of NEC Contracts

Tokyo NIKKEI SANGYO SHIMBUN in Japanese 9 Mar 82 p 7

[Text] It has become certain that the value of Nippon Electric Company's (NEC) FY-81 Defense Agency contracts for communications and control apparatuses will approach 30 billion yen. Since the beginning of March, the last month of this fiscal year, NEC has entered the final spurt period for obtaining orders for defense-related apparatuses. According to NEC's government sales group, the total amount of contracts in FY-81, including direct orders by the Defense Agency's Central Procurement Office, shows a steady increase and is expected to be 29 billion yen, a 3.6-percent increase over last year.

The actual value of NEC's contracts in FY-80 was 22,313,000,000 yen. This was only the portion directly received from the Central Procurement Office. If the orders received from the Ground, Maritime, and Air Staff Offices are added, the total reaches approximately 28 billion yen. This has been further increased to almost 30 billion yen in FY-81. NEC's defense division supplies mainly communications equipment such as radars and microcircuits and control apparatuses such as missile guidance systems. These apparatuses are indispensable for almost all defense equipment, such as airplanes, escort warships, and tanks. In addition to an increase in the defense budget, because current equipment--particularly aircraft--are in the process of being replaced now, for example the F-15 is now in the process of deployment, NEC's contract total has been steadily increasing. With further budget increases in the next fiscal year and construction of not only single items but also a "central command system" for the purpose of mobilizing and commanding each Self Defense Force unity promptly and properly in case of emergency, a large increase in orders for communications and control apparatuses is expected. For this reason, it appears certain that NEC's contract total in FY-82 will exceed 30 billion yen.

Remodeling Phantoms

Tokyo NIKKAN KOGYO SHIMBUN in Japanese 4, 5 Mar 82

[Article by reporter Kunihiko Tanabe]

[4 Mar 82 p 11]

[Text] Is the Phantom, a great airplane which has changed the concept of fighter aircraft and has been playing the main role in Japan's air defense, a rogue that likes to fight too much? Its debut in Japan was really sensational. Because of its extraordinary high performance, it caused a big debate on defense. In the end, former Defense Agency Director General Masuda made it clear in the Diet in 1968 that "The Phantom is not to be equipped with bombing capability," and therefore, the Phantoms came in force without striking power. However, because the bombing capability will be restored in the Phantom trial remodeling project that is intended to extend its service life and improve its capability, the aircraft has upset the Diet again and has even caused suspension of the execution of the budget. Compared with the case of the F-15 Eagle, a new air defense ace that will replace the Phantom and which was approved by the Diet without any obstacle, the Phantom is in striking contrast and is destined to be a rogue. The Defense Agency is planning to prolong the life and improve the capabilities of the "aged" Phantom, whose flying hours will soon be exhausted, and open the road to "reemployment" of the Phamtom. Meanwhile, the defense industry is also eagerly awaiting the project, which will cost over 100 billion yen. Therefore, I have explored the situation surrounding the Phantom remodeling project.

The F-4 Phantom EJ, which has been the star of Japan's air defense since the latter half of the Showa 40's (1970-74), has surrendered the leading position as a fighter-interceptor to the F-15J. The life of a Phantom is 3,000 flying hours. The Phantoms were gradually to retire starting in FY-86 and to disappear completely by about 1990, if the Defense Agency did not do anything about it. At present 132 Phantoms are assigned to scramble in Chitose (Hokkaido), Hyakuri (Ibaragi Prefecture), Komatsu (Ishikawa Prefecture), and Tsuiki (Fukuoka Prefecture).

The Defense Agency intends to prolong the life and improve the capability of the Phantom to strengthen the air defense network, which is expected to consist of only F-15 fighters from the mid-Showa 60's (1990-). According to the FY-78 Mid-Term Operations Estimate, 100 F-15 fighters are to be eventually assigned for duty, however, the F-104 Starfighters and Phantoms are to disappear from duty. As a result, the total fighter airplanes will number approximately 170, including about 70 F-1 support fighters. That will be far from the "approximately 250" fighter-interceptors specified in the national defense plan outline. On the other hand, it is not easy to ask for additional purchases of F-15's, which cost over 10 billion yen apiece. That is especially true for a government with a shortage of revenue sources. Consequently, the Defense Agency decided to adopt a plan to extend the life of the Phantom from 3,000 to 5,000 flying hours and to prolong the use of the Phantom by about 10 years.

Although old, the Phantom is the world's best selling fighter aircraft, with over 5,000 produced. In Japan, Mitsubishi Heavy Industries as the main contractor has manufactured 143 Phantoms. The Phantom is a large fighter whose body is approximately the same size as the B-29's which struck Japan with terror as flying fortresses during World War II. The Phantom is mounted with two J79-GE-17 jet engines and can fly at a maximum speed of Mach 2.4 with the strong power of the engines. The original Phantom model could carry four Sparrows (AIM) and four Sidewinders (AIM) in addition to over 6 tons of bombs. Its cruising range is an extremely long 4,200 km. Because of all these characteristics, the original type of Phantom appeared to be a very aggressive fighter-interceptor that could threaten neighboring countries. For this reason, the bombing system, nuclear control system, and air-to-surface missiles were removed from the original configuration, to make the F-4EJ.

Based on the result of an investigation, the Defense Agency guarantees that the Phantom is still capable of fighting on the front line if electronic apparatuses are replaced with the newest types, and the aircraft is remodeled so that the latest air-to-air missiles and anti-ship air-to-surface missiles can be carried. The Defense Agency has requested, so to speak, that "aged" Phantoms approaching retirement be reemployed. In order to convert the Phantoms into remodeled F-4's which can rival new generation fighters, the Defense Agency has decided to draw up two plans to prolong their service life and to improve their capabilities.

According to the plan to prolong their service life, the Defense Agency will purchase 25 VGH recorders with a budget of 700 million yen during FY-82. A VGH recorder will be installed in one out of every six Phantoms to obtain data on velocity, gravity, and height. In addition, C-A data, the actual record of use of each aircraft, will be obtained from a load frequency meter which was installed in every aircraft at the time of manufacture. This type of measure to prolong service life is called ASIP in the United States. Japan's Defense Agency is supposed to prepare software for the ASIP by FY-83 and start operation as of FY-84.

According to the plan, instead of using the present method of determining the service life of an aircraft when a representative aircraft of the type is wrecked, the Defense Agency will determine the service life of each aircraft separately by examining the detailed data of each aircraft. In predicting the future degree of wear of each aircraft, the Defense Agency will employ necessary checks and repairs for each aircraft. In addition, the limit of wear of each structural part will be checked in detail. The Defense Agency cannot tell for sure if the prolongation will be 2,000 hours or only about 500 hours until it examines the result of its surveys.

There is no particular problem in prolonging service life. The movement to develop software in Japan has been rising in the defense industry. As for the improvement of the capabilities that is the other side of the remodeling project, however, the current session of the Diet has suspended the execution of the FY-81 budget. The restoration of the bombing system in the Phantom has greatly stirred up the opposition parties.

[5 Mar 82 p 9]

[Text] Phantoms close to retirement will be converted into extraordinary aircraft--since the Japanese are skillful, there is the possibility that it may happen. In response to a remodeling project which requires 8.5 billion yen in FY-82, speculation about an extraordinary aircraft ran thousands of miles at a full gallop and the Diet has been giving red signals one after another to measures to improve the capabilities of the "aged" Phantom.

Certainly, a big experiment on the Phantom is about to be made. Although the Phantom belongs to the previous generation of fighters, the remodeling project is aimed at modernizing the electronic apparatuses carried in the Phantom and at strengthening its missile power while making the best of the Phantom's flying speed of Mach 2.4. Although the exterior will remain the Phantom itself, the interior will be designed by picking up apparatuses from the most advanced airplanes. It is no wonder that the project is considered in some respects an experiment to absorb hungrily every merit of the F-15 fighter-interceptor, the F-16 light combat attack aircraft, the A-10 anti-tank attack aircraft, and the Alfajet support fighter.

The capability improvement measures are: (1) improvement of the fire control system, (2) strengthening and expansion of missile-carrying capability and (3) improvement of bombing capability. The most outstanding feature of the design is the installation of a central computer, which the present Phantom does not have, and the collective processing of all information. If the same IBM central computer as the one in the F-15 is used, the remodeled F-4 can be armed with air-to-air missiles--AIM-7F (the latest Sparrow) and AIM-9L (the latest Sidewinder). If this computer is installed, the remodeled F-4 will incidentlally also possess bombing calculation capability. However, if it is the computer used in the F-15, the bombing capability of the remodeled F-4 will not exceed that of the F-15. It is unnecesary to cite examples of Zero fighters and Hayabusa fighters which were loaded with bombs and torpedoes and sallied forth. Fighters are all equipped with some bombing capability. In the case of the Phantom, however, because of its extraordinary high performance and separate installation of a bombing computer, the removal of the bombing capability was possible.

As for an FCS which locks onto a target, the Westinghouse APQ 120 will be replaced by the Westinghouse APG 66 that is installed in the F-16. Although both the APQ 120 and the APG 66 are made by Westinghouse, the former is an analog pulse radar while the latter is a digital pulse doppler radar. This change will greatly increase the look-down capability, which is presently non-existent when flying at low attitudes. The doppler effect does not work in the case of tanks and buidlings on the ground. Therefore, targets must be identified visually by the pilot. Nevertheless, the APG 66 will be extremely threatening to warships on the ocean.

A pilot sees a shadow of an airplane in the headup display and takes action to engage it. As a headup display system, the Defense Agency plans to use the one which was jointly developed by West Germany and France for the Alfajet support fighter. As for the inertial navigation system (INS) which flies the airplane to its destination without guidance, the LL 39 (Litton of the United States) from the A-10 anti-tank attack airplane will be used. Although the Defense Agency explains that the LL 39 is cheaper than the INS of the F-16, the combination of the INS from the A-10 and the FCS from the F-16 will give new characteristics to the remodeled Phantom, and that concerns me.

The Defense Agency persistently defines the plan to prolong the service life and improve the capabilities of the Phantom as an effort to retain the fighter-interceptors. The Defense Agency plans to protect Japanese airspace with Phantoms together with the F-15's until the Showa 70's (1995-2005), when self-developed future fighters will begin flying. For this reason, it is necessary to replace the AIM-7E, whose firing speed is Mach 3.5 and whose range is 25 km, with the AIM-7F, whose range is 44 km even though the firing speed remains the same in the remodeled Phantom. Also, because the remodeled F-4 can separately fire 7 km and 10 km range Sidewinders, its capability to handle dogfights within these ranges will greatly be improved. With these reasons in the background, the Defense Agency even says that the primary mission of the Phantom is that of a fighter-intercepter, and it will not object to cancellation of some of the items when mass production of the remodeled F-4's begins in 1986.

Nevertheless, it is true that the remodeled Phantom will collect the functions of the world's most advanced support fighters and attack airplanes. Reviewing the history of fighter airplanes, the unrivaled Zero fighters were shot down as if they were red dragonflies during the final stage of World War II. The uniformed officers' idea that "the more exclusively defensive Japan's defense is, the more necessary excellent aircraft are to prevent enemy intrusions in advance," coincides with each item of the Phantom remodeling project.

Recently the idea that the distinction between fighter-interceptors and support fighters is unnecessary has been spreading through the Air Self Defense Force. It holds that in case of an emergency there is no time to choose battlefields and all aircraft will have to be mobilized. For this reason, the Defense Agency seems to want to say that fighters must be allround attack aircraft, and the restoration of the Phantom's bombing capability is not incidential. The Phantom happens to be close to the end of its normal flying life and just short of the time when it will be worthless as a fighter. In their dreams uniformed officers have seen that the world's best attack aircraft can be produced at a cost of about 1 billion yen in the case of mass production if measures are taken to prolong the service life and improve the capabilities of the Phantom, which would otherwise soon be almost without value. The idea is that it is better to depend on "the second life" of the Phantom to fight support battles where the probability of damage to aircraft is high instead of using the expensive F-16. The Defense Agency is planning to remodel 100 Phantoms. Mitsubishi Heavy Industries, the main contractor, and various electronic apparatus manufacturers are casting covetous looks at the remodeling project, since it means that unexpected extra technological and pecuniary gains will fall into their hands.

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SCIENCE AND TECHNOLOGY

INDUSTRIAL ROBOT PRODUCTION TECHNOLOGY DISCUSSED

1981 Industrial Robot Fair

Tokyo DENSHI GIJUTSU in Japanese Vol 24, No 1, Jan 82 pp 49-52

[Article by Ryosuke Masuda and Takashi Mizutani, both of the Control Engineering Department, Tokyo Institute of Technology: "Sensors, Control Functions, and Mechanisms Which Drew Attention (From the 1981 Industrial Robot Fair--Photogravure Commentary)"]

[Text] The Era of Robots With Intelligent Functions

We are having a robot boom today. Robots of all kinds, from industrial robots to recreational robots, have caught the public eye. The industrial robot fair held recently proved this point very well. Never before have so many people attended an exhibition of industrial machinery. One had to wait in line a long time before entering the hall, and even after entering the hall, one had to push through the crowd in order to be able to see.

Having been widely publicized by newspapers and TV, the juice serving robot (Photogravure 14) above all was especially crowded with people. This robot is capable of recognizing a number of words such as "orange" and "grape" from a voice input, and according to the program's choice, the robot will pick up a bottle of juice, remove the cap, and after checking it with a sensor, pour the juice into a cup to serve. The existence of such a robot with intelligent functions, which comes just a little bit closer to the image of a "robot" held in people's minds, must have stirred people's interest.

Instead of the term "intelligent robot," which has become quite popular in recent years, "robot with intelligent functions" is used here for the following reasons: Although the control technology employed in the industrial robot today may be quite advanced, the robot does not possess true intelligence or the ability to take action automatically according to the circumstances. Rather, the capabilities of the robot today remains at the level of intelligent functions* including judging, thinking, learning, and adapting through detection and memory.

*The term "intelligent functions" is defined as the functions a robot should possess in the draft definition of robot terminology (Research Report No 2 concerning standardization of robot; Japanese Industrial Robot Society, 1976).

Control functions have been significantly improved in recent years, thanks to the advancement of microelectronics. The statement "microprocessor is being used" always appeared in the catalog or panel just a few years ago, but not today. This is probably because microprocessors, whether 8-bit cr 16-bit, are being utilized so commonly that limitations on the scale capacity and computation functions due to hardware have been relaxed to some extent.

Therefore, the problems encountered today in the construction of robots are related to the sensors and the software used in the control system. A number of new attempts in these areas could be seen in the recent robot fair, including an attempt to raise the level of intelligent functions to that suitable for industrial application. In the field of industrial robots, the era of robots with intelligent functions consisting of sensors and associated processors together with control software may continue for some time to come.

In this article, the sensor functions and the control functions of the intelligent robot, together with the mechanisms which are indispensable for producing the concrete action function of the robot, will be discussed centered around the machines displayed at the industrial robot fair.

Activity of Sensors Has Only Begun

Sensor-controlled robots were the type of robots most widely expected at this robot fair. However, there were only a few examples with unique sensor application; it appeared that the time was not yet ripe for extensive and effective application of sensor technology to robots.

On the other hand, in spite of the fact that an excellent vision system as a single entity was successfully developed by Fuji Electric and Tokyo Electron (the U.S. Automatrix Co), the link between this vision system and the robot movement has not been well developed. This delay is probably due to the great difficulty encountered in robot control software when movement control is to be accomplished by vision input.

The sensor control which is in greatest demand and is also used most widely today is that used for searching the welding line used on the welding robot. There were a few different formats of this type of control on display. One of them was the vision system used on Kawasaki Heavy Industry's PUMA robot (Photogravures 1 and 4). In the beginning, when the machine is in the welding line discrimination mode, this system shines a slit of light onto the work to be welded. The light reflected from the work is received by a photodiode array camera via an optic fiber and the signal is processed. By this process, the location of the welding path along an L joint or a butt joint can be determined. This method uses a two-pass format consisting of the discrimination mode and the welding mode in order to achieve a highly reliable operation.

The proximity sensing format, which was used on Hitachi Limited's "Mr Aros" robot (Photogravure 8), is a method in which the location of the welding line is continuously checked and determined during the welding process. This method has been in use for some time now.

The contact format was used in the welding robot of Shinmeiwa Industry. In this method, the welding wire itself is used as the contact point, and the welding line along an L joint is determined by four points which are searched prior to the welding operation. This format is convenient for practical applications because no speci. . sensor elements are required.

Another method of on-line control of the welding line without the use of a sensor element, which was used on Yasukawa Electric's welding robot, also caught people's attention. This method utilizes the welding current itself as the feedback signal. This method is quite effective where the nature of the welding line is known to some extent.

The accuracy of arc-welding can be improved through use of these on-line or off-line sense functions. However, the most desirable method is one which is capable of solving problems related to strain in the work being welded and to optical and electrical noises.

"Pana Robo," a product of Matsushita Industrial Machinery (Photogravure 3), was one in which the vision system was utilized for the general operation. Although it was a demonstration operation, a certain figure pattern was picked up by a camera and the data was fed into a processor, which extracted the center location (X,Y) and the angle of inclination (θ) of the figure. The operation table was then positioned by translating and rotating it according to X-Y-θ. The figure pattern was discriminated, a program was chosen, and the motion of the arm was actuated according to this program.

Another Pana Robo had a photo sensor in its hand, and it was able to sort objects by detecting the color of the object (see Photograph A). This robot was able to discriminate five or more different colors. It appeared to have a highly practical applicational value.

Nippon Electric's keyboard assembly robot (Photogravure 2), together with the arc-welding robot, is usually considered one of the goals of using a robot. This robot was capable of detecting pressure on its arm through measurement of the deformation of a spring in its arm's driving mechanism, and the assembly operation was carried out with a force feedback control. Besides these, robots with sense of touch control have also been developed by Hitachi, but no outstanding assembly robots with sensors were on display this time. The force control technology should be pursued further in relation to the compliance characteristics of the SCARA type robot, which will be discussed later.

Balance Between Control Functions and Operability

The robot's control functions on the servo level and the robot's operability characterized by the ease with which it can be taught or programmed will be investigated next.

In regard to the servo control level, the continuous path control is greatly in demand for the control of such operations as painting and welding. For example, the welding robots developed by Hitachi (Photograph B) and by Shinmeiwa (Photogravure 5) are capable of smoothing the path by performing three-dimensional linear or arc interpolation through a number of given teach points. This capability enables the robot to connect any two given points in space with an arbitrary curve. This function, together with the function for smoothing the stop points and nonstop points, enables the robot to execute a smooth movement which could not be realized in conventional robots.

Another control function concerns effective coordination with the mechanism--that is, as more and more robots with jointed construction appear, these robots are equipped with an appropriate coordinates transformation function so that they can operate along a path in any coordinate system. As a result, horizontal and vertical movement of the arm, and movement to maintain a fixed wrist orientation are greatly facilitated. Moreover, the programming information may be dealt with in a specific coordinate system such as the rectangular coordinate system. This feature is indispensable for a robot with multiple degrees of freedom. The interpolation function and the coordinates transformation function require a considerable amount of computation. Therefore, the key factors should be simplification of the computation format and improvement of computation speed.

The operating system is becoming more and more advanced and, as far as teaching and programming are concerned, program selection and modification can be easily carried out not only during the teaching period but also during the operating period using an external signal.

Now then, since the control of robots by microprocessors became commonly in use, its operability has become a focus of attention. All controllers consist, in general, of a keyboard and a CRT display for monitoring, and these controllers have been simplified to make them easier to operate for on-site application.

A control device consisting of a flat touch keyboard and a 9-inch CRT used on the arc-welding robot of Mitsubishi Electric (Photograph C) is a typical example. The robot program data, welding conditions, and its relationship to the external jig control can be displayed on the CRT screen. This system is very effective not only for teaching but also for monitoring.

The robot languages employed to increase the effectiveness of teaching and programming the robot include Sankyo Seiki's SERF and Kawasaki's PUMA language, VAL. Using SERF, designation of the XYZ coordinates and designation of speed, together with the sequence command and the loop command connecting these points can be programmed and entered into the system through the keyboard. To utilize this function it is necessary to learn the language, but it is worthwhile because the language facilitates the description of a complicated operation and allows expansion into sensor control. Robot language is considered to become even more indispensable as the robot functions become more advanced. At present, it is highly desirable to have more robot languages introduced so that the use of robot language can become more popular.

Morphological Evolution of Robot

We will continue to review the details of the robot fair from the viewpoint of the mechanisms.

An overall trend, characterized by the transition from conventional robot operations consisting of transporting and painting to more advanced operations such as welding and assembly, was apparent. A variety of innovations and changes have been introduced into the shape of the robot itself and the ways in which robots are utilized.

One of the changes concerns the type of robot. Traditionally, a typical industrial robot belonged to either the rectangular coordinate type, the cylindrical coordinate type, or the polar coordinate type. Robots of these types have largely disappeared, and the number of jointed robots resembling human beings has increased significantly this year. This is because a robot performing welding or assembly must be able to move freely in all directions within the operating space, and the jointed type has the advantage over the conventional type for this type of application. Kawasaki's PUMA is a typical example. This model was designed mainly for precision operation, and it comes in several different sizes. It appears that this robot is well prepared to deal with various applications that may come up in the future (Photogravure 4). A similar type of robot was also used in the welding operation by Dainippon Machinery, demonstrating the superior movability of a robot of this type.

On the other hand, a number of jointed robots with a new shape, called SCARA, were also on display. As shown in Figure 1, the rotational axis of each joint of this type of robot is vertical. This feature is the main difference between the SCARA type and the PUMA type. The functions of the SCARA type robot emphasize operations in a horizontal direction. The SCARA type robots possess one unique design concept: that is softness (compliance) in the robot's horizontal action. Instead of highly precise and rigid action, the robot's movement is in part influenced by external pressure so as to carry out the operation smoothly. Take the case of inserting a rod into a filleted hole, for example. If this operation is carried out by the conventional high-precision control, the rod and the hole may fight one another due to unavoidable positioning error. On the other hand, even if the two are slightly misaligned, a robot with compliance can align them without undue strain, because of the softness in its horizontal movement. Examples of this type of robot were displayed by Nitto Precision Industry (Photogravure 9) and Sankyo Seiki (Photogravure 10). In Pelten's PUHA (Photogravure 11), the weight of the arm was reduced significantly by an innovative design in which all the driving units were concentrated in its base. Unfortunately, there were no firms which designed their demonstration to highlight the compliance. The utility value of compliance has not yet been fully evaluated, according to an explainer. It will be a great pleasure to watch its future development, as the topic of compliance was discussed at the 11th International Industrial Robot Symposium held 7-9 October in the Japan Federation of Economic Organizations Hall. The future trend will be to strive not only for a more highly accurate action function but also for smoother operation through adaptability in movement.

As for the robots for welding, no significant changes either in the mechanisms or in the types came to attention. However, the goals have been shifted from conventional spot welding to arc-welding, which is more difficult to perform and in which the deformation of the work must be taken into consideration. As

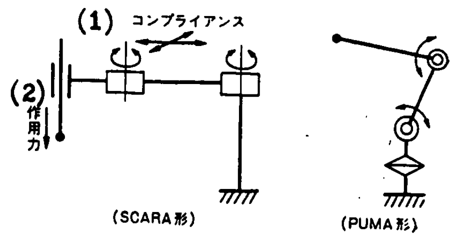


Figure 1. Diagram of Robot's Degree of Freedom

Key: (1) Compliance (2) Acting force

more problems inherent to the arc-welding operation are uncovered, more new mechanisms will be invented. In addition, there is a trend to replace human operators by robots for all welding operations, where the environment is harmful to human operators. For this reason, too, the robots used in welding operations must not only possess advanced functions but must also be easier to operate.

Another way of utilizing the robot was demonstrated by the robot displayed by Yasukawa Electric (Photogravure 12). An ordinary type of robot is placed horizontally, and instead of using the robot to carry the welder, the welder is approached by a robot carrying the work. To be sure, not only will many new types of robots be developed in the future, but many ideas concerning utilization of robots will also be invented.

As to other individual ideas, the wrist of Hitachi's robot (Photogravure 6) provided an increasing example. This is a mechanism capable of working in a limited space such as painting the inside of a box. Other innovations to expand the robot's capabilities could be seen in various forms, including introduction of a linear motor into an actuator by Nippon Electric (Photogravure 13). Furthermore, many more ideas must have been put to good use in many parts of the robot which could not be seen from outside.

The robot fair this year was reviewed briefly mainly from the viewpoint of mechanisms. In spite of the great potential the robot possesses, its progress does not appear to be as rapid as that of electronics technology. We hope that robots in newly evolved forms will soon appear through innovative technological development.

Conclusion

Robots, including those appearing in cartoons and science fiction, are discussed widely on television and in magazines today. Probably because of this, a great many people of all age groups came to see the robot fair this year. The elementary school pupils, who were found in large number among the spectators, may have been puzzled by the industrial robots which look so different from the image of robots held in their minds and, at the same time, gained new understanding about robots.

But there are still many possibilities for the robot. The range of work assigned to the robot can only grow wider and more advanced in nature. The robot, without a doubt, will make progress steadily by overcoming many trials. Many new phases of robots will certainly be revealed at the next robot fair. My confidence in its future progress was sufficiently assured by the youthful future technologists I saw at the robot fair.

PHOTOGRAVURE CAPTIONS

1. "Treat me like an operator" was the catch phrase of Kawasaki's PUMA, a computer-controlled robot.

2. Nippon Electric's keyboard assembly robot.

3. Matsushita's Pana Robo, an arc-welding robot, caught attention as a robot capable of applying its vision system to an ordinary operation.

4. Kawasaki's PUMA performing welding operation; aiming at greater reliability in operation through application of sensor technology.

5. Shinmeiwa's Robel, a plasma shearing robot; carrying on board a 16-bit microcomputer.

6. Hitachi's spray painting robot "PARKER" with a microcomputer.

7. The wrist of Hitachi's spray painting robot.

8. Hitachi's "Mr Aros," a welding robot, with noncontact type sensor, carries out welding operation as it measures.

9. A programmable robot, "Picmat SCARA," for automatic assembly (Nitto Precision Industry).

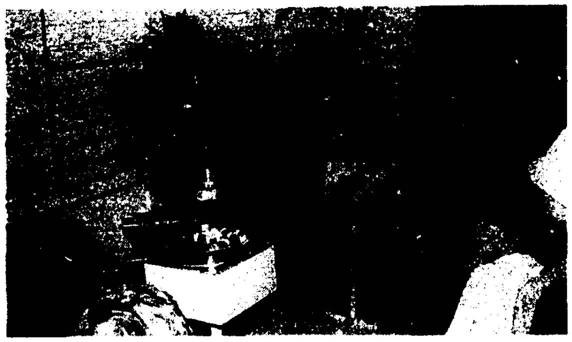
10. "SKILAM series" multiple-jointed robot controlled by microcomputer (Sankyo Seiki).

11. Precision assembly robot "PUHA" (Pentel) concentrates all driving units in its base to reduce the weight of its arm.

12. Yasukawa Electric's welding robot "Motoman." A robot carrying work approaches a stationary welder--an interesting idea.

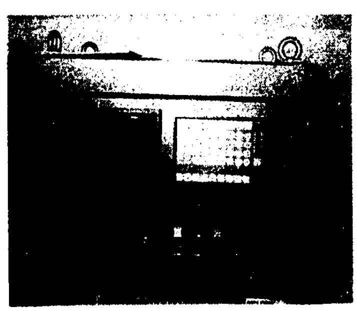
13. Nippon Electric's precision assembly robot "Model A," with actuator driven by linear motor. New possibilities are uncovered.

14. Nippon Electric's juice serving robot can recognize spoken words such as "grape" and "orange." It opens the bottle and serves juice in a cup after checking it with a sensor.



Photograph A. Robot capable of discriminating colors (Matsushita Industrial Machinery)

Photograph B. Robot capable of arc interpolation (Hitachi Ltd)



Photograph C. Robot control panel (Mitsubishi Electric)

We can cite the qualitative improvement of the robot itself as one of the factors supporting the robot boom in recent years. The capabilities of industrial robots are being upgraded by leaps and bounds, as indicated by words such as diversified and multifunctional used to describe them. In support of all this is the newest electronics technology such as LSI, microcomputer, and sensor.

"The 1981 International Industrial Robot Fair" (sponsored by the Japanese Industrial Robot Society and NIKKAN KOGYO SHIMBUNSHA) was held at the Tokyo Industrial Sample Market Assembly Hall in Tokyo-Haruumi for 5 days starting 8 October last year amidst this background. This robot fair, which was the fourth of its kind, was represented by 36 robot makers (the largest so far), each displaying its own unique machine, and the fairground was crowded with the spectators day after day.

In connection with this special issue, some examples of "robots with intelligent mechanisms" which caught most attention at the fair are introduced herein together with a report written by Messrs Masuda and Mizuta of the Tokyo Industrial University.

Kawasaki Heavy Industries' PUMA

Tokyo DENSHI GIJUTSU in Japanese Vol 24, No 1, Jan 82 pp 53-56

[Article by Yasuhiro Kubota, director of Hydraulic Machinery Business Department, Kawasaki Heavy Industries: "PUMA Robot System"]

[Text] The PUMA (Programmable Universal Manipulator for Assembly) robot system, consisting of a multiple-jointed, electrically operated robot with artificial intelligence was realized as a result of an R&D effort on the computer-controlled robot system which lasted more than a decade. The PUMA was developed not merely to replace human muscular labor but also to simulate human dexterity.

The medium-scale robots of the 500 series in earlier days were each developed for the purpose of replacing a human operator and to do assembly work along with the human worker, so their shape and size were patterned after the human figure and their range of action was also comparable with that of a human being.

The minirobots of the 200 series developed later were about half the size of the 500 series. These minirobots were characterized by their compactness (shoulder height 33 cm, arm length 40 cm), light weight (robot body weight approximately 7 kg), high speed (1.5 m/s), and high accuracy (±0.05 mm). They were used mainly for the assembly of electronic parts such as inserting resistors, condensors, and transistors into the printed circuit board.

In response to a demand for power in addition to all the other attributes of the PUMA robot--including dexterity, high speed, and high accuracy--robots of the 700 series which are 1.5 times bigger in size and four times larger in load-carrying capacity (10 kg) than the 500 series were developed last summer.

These three types of PUMA robot system were developed on the basis of the same design concepts (such as structure and control format) except for the difference in size. Therefore, they are all compact, light weight, and made with structural precision. They can move faster (1-1.5 m/s) and more accurately (±0.1-0.05 mm) than the human being can. Moreover, the robot's arm can be freely switched from left to right, and vice versa. These robots can even reach the back side of the work object, and since the robot's shoulder can rotate both forward and backward, they can perform operations behind them, so to speak, as easily as in front of them.

The robot's movements are all calculated and processed by the microcomputer contained inside the robot in real-time, so any arbitrary spatial linear or curvilinear motion can be carried out with a high degree of accuracy. Moreover, the software system in support of this robot system has a versatile robot language, "VAL," at its disposal, so the user is able to teach his robot any movement he desires very easily using this program language.

Therefore, PUMA robots, which can work along with human workers, are being used widely in diversified fields for various handling operations including arc-welding, inspection and measurement, in addition to performing assembly of electronic parts and machine parts.

The System Components

The PUMA robot system consists of the following basic components: the robot, the control device, and the teach box. To make the robot do actual work, a program must be composed first and the robot must be taught to behave. The following additional components are necessary to accomplish this task: a CRT terminal (or a typewriter) to instruct the robot to move, a pneumatically operated hand, and an external signal interface (I/O module). In any case, these can be simply equipped as an option. In addition, an external auxiliay memory device consisting of a minifloppy disc may also be used to temporarily store the program prepared by the user. Figure 1 provides a block diagram of this system.

The software system VAL, which controls the entire system, is stored in a PROM inside the control device. VAL is an advanced program language used for robot control and is equipped with the following functions: 1) maintains surveillance of the system state, 2) compiles the user program and executes it, and 3) controls the movement of the robot. The user may also use this language to give commands and make the robot perform various operations.

1. Robot Body

The external appearance of the robot body (Model 500), its main dimensions, and its range of movement are shown in Photograph 1, Figure 2, and Figure 3, respectively.

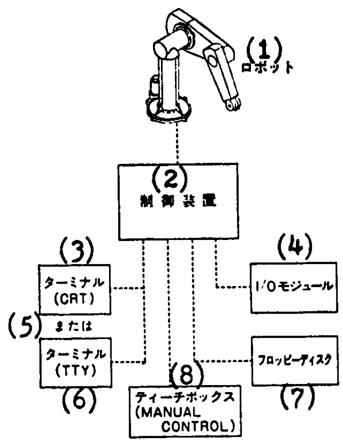
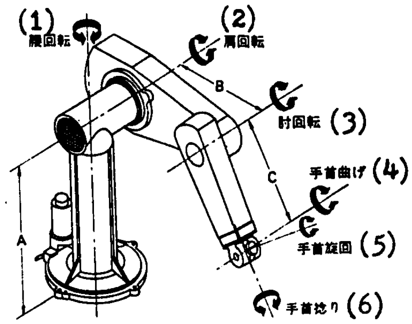


Figure 1. PUMA Robot System Block Diagram

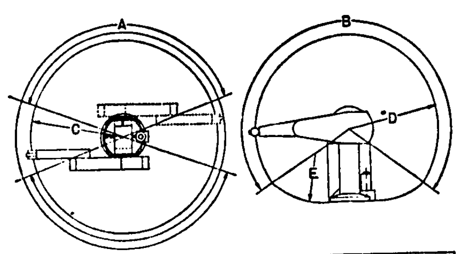
Key:
(1) Robot
(2) Control device
(3) Terminal CRT
(4) I/O module
(5) Or
(6) Terminal TTY
(7) Floppy disc
(8) Teach box (Manual control)



	小型 Small 200	中型 Medium 500	大型 Large 700
A	330mm	670mm	1030mm
B	203mm	432mm	650mm
C	203mm	432mm	600mm

Figure 2. Main Dimensions of PUMA Robot

Key:
(1) Waist rotation
(2) Shoulder rotation
(3) Elbow rotation
(4) Wrist bending
(5) Wrist rotation
(6) Wrist twisting



	A	B	C	D	E
小型 Small 200	315°	320°	406mm	406mm	203mm
中型 Medium 500	320°	250°	864mm	864mm	432mm
大型 Large 700	320°	250°	1250mm	1250mm	600mm

Figure 3. Robot's Action Range

Photograph 1. External View of PUMA Robot (500 series)

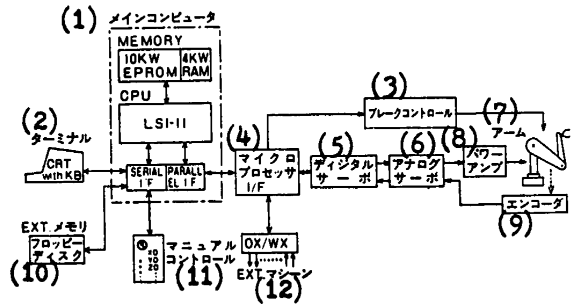


Figure 5. Control Device Block Diagram

Key:

(1) Main computer
(2) Terminal
(3) Brake control
(4) Microprocessor I/F
(5) Digital servo
(6) Analog servo
(7) Arm
(8) Power amplification
(9) Encoder
(10) (External memory) Floppy disc
(11) Manual control
(12) External machine

This control system is comprised of a microcomputer system consisting of a CPU (LSI 11/2), a PROM containing the system software VAL, a RAM for the user program, a serial I/F controlling terminal-external memory-teach box communications, a parallel I/F in parallel with the control circuit of the robot body itself, together with the electric circuits for the control of each motion axis and a DC power source. All circuits necessary for the control of the PUMA robot system are contained in it. The external shape of the control device is such that it can be rack-mounted and its weight is 45 kg, so it can be easily moved around.

3. Peripheral Devices

1) Terminal: The terminal may consist of a keyboard (standard typewriter format) and a video display unit (CRT), or a printer (TTY). The user may use this terminal to edit the user program in VAL and also to execute it. This terminal may also be used to display the robot status. The terminal may be disconnected from the control device while the robot is moving according to the user program.

2) Floppy disc: The floppy disc drive is capable of storing the user program and position data, and if necessary, it can read out data to the RAM of the control device. The power to this device is supplied by the control device, so the device becomes operational as soon as the special cable is connected (applicable disc: 4.5-inch minifloppy disc).

3) I/O module: The PUMA robot system must work in concert with other equipment such as a conveyer in an actual operation situation. Therefore, the

The robot's degree of freedom consists of three basic axes: waist rotation (JTI), shoulder rotation (JT2), and elbow rotation (JT3); plus three wrist movements: twisting (JT4), bending (JT5), and rotating (JT6)--a total of 6 axes. Depending on the type of work, the robot may also be operated with five-axis movement by deleting the wrist twist.

Each axis is driven by a DC servomotor through a speed-reducing gear train. The driving unit consists of a DC servomotor, an incremental encoder, and a potentiometer. The basic axes are equipped with electromagnetic brakes, so in case of power failure, the robot's attitude can be frozen in order to prevent any damage that may result from contact between the robot and the incidental equipment. In order to realize high-speed action, the dynamic balance of the structure was carefully considered through extensive measures, including high-strength member construction with cover, use of light alloy material and die-casting technique to achieve lightweight design, plus miniaturization of mechanism design.

Moreover, to insure reproducibility with a high degree of precision, in addition to the lightweight high-rigidity design described above, a special backlash adjustment mechanism was introduced to the speed-reducing gear train. Thus, the desired degree of precision was attained.

2. The Control Device

The external appearance of the control device and its block diagram are shown in Figure 4 and Figure 5, respectively.

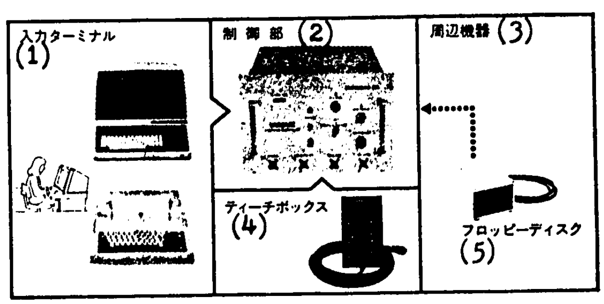


Figure 4. External View of the Control Device

Key:
(1) Input terminal
(2) Control unit
(3) Peripheral equipment
(4) Teach box
(5) Floppy disc

PUMA robot system must be equipped with a line through which it can receive signals from other equipment in order to know their status and also to transmit signals to the outside equipment. The I/O module is equipped with these functions, and it is connected with the control device by a flat cable. It is constructed in such a way that it can be rack-mounted.

4) Teach box: The teach box consists of various switches for operating the robot and a display unit to display the message concerning the system status issued by the control device. In the teach mode, the speed of manual operation and the position and orientation of the robot's wrist can be set by the teach box. Or, the user program can be stopped during its execution, or the speed of the robot can be changed during its operation by the teach box. By switching to "free mode," the robot can be operated manually. Furthermore, the pneumatically operated hand can be opened or closed, or the coordinate system used (to be described later) can also be changed by the teach box.

Specifications and Characteristics of the Robot

The specifications of the robot body and the control device of the PUMA 500 series are summarized in Table 1, and their characteristics are as follows.

1) Superior Operability

(1) Lightweight and compact construction with multiple degrees of freedom: it occupies only a small space, so it can be installed easily anywhere and becomes operable as soon as it is connected to a commercial power source.

(2) Easy to Teach (Program)

The robot can be taught in robot control language VAL.

The robot can be taught by the teach box in various action modes with respect to: a) each motion axis, b) absolute coordinate system (X,Y,Z,), and c) wrist coordinate system.

(3) Program changes can be implemented even during the repeat action period.

2) Diversified Control and Advanced Functions

(1) Applicable to all control modes including PTP (point to point) and CP (continuous path) control of the work orientation.

(2) High accuracy (±0.05-0.1 mm), high speed (1-1.5 m/s).

(3) Compatible with vision sensor, touch sensor, or force sensor control.

3) High Reliability

High reliability is insured by a combination of a maintenance-free robot body and a controller containing LSI-11.

Table 1. Specification List

Model			500 series (medium type) 550	560
Body specifications		Number of axes	5	6
Body specifications	Action range	Waist rotation (JT1)	320°	
Body specifications	Action range	Shoulder rotation (JT2)	250°	
Body specifications	Action range	Elbow rotation (JT3)	270°	
Body specifications	Action range	Wrist twisting (JT4)	-	300°
Body specifications	Action range	Wrist bending (JT5)	200°	
Body specifications	Action range	Wrist rotation (JT6)	520°	
Body specifications		Load capacity	2.5 kg	
Body specifications		Static load	6.0 kg (wrist tip)	
Body specifications		Repeat positioning accuracy	±0.1 mm	
Body specifications		Maximum speed	1,000 mm/s	
Body specifications		Machine weight	approximately 55 kg	
Control specifications		Control format	Computer-controlled electric servo	
Control specifications	Control format	Free	Each axis can be moved manually freely	
Control specifications	Control format	Each axis control	Each axis can be moved independently	
Control specifications	Control format	Absolute coordinate control	Wrist tip moves in the XYZ coordinate system	
Control specifications	Control format	Wrist system control	Action in the wrist tip (work) coordinate	
Control specifications	Control format	Program control	Action according to user program	
Control specifications		Program language	VAL (number of commands= approx 100	
Control specifications		Program number	No limit. Conditional and unconditional branching may be introduced freely	
Control specifications		Interlock	Transmission (OX) and reception (WX), 8 circuits each (expandable to 32 circuits)	
Control specifications		Power source	100/200/220 VAC, 50/60 Hz, 1,500 W	
Control specifications		Dimensions	320 (H) x 490 (W) x 610 (D) mm	
Control specifications		Weight	Approximately 45 kg	
Options		TTY terminal	300 baud, RS-232 C	
Options		CRT terminal	9,600 baud, RS-232 C	
Options		Auxiliary memory unit	Minifloppy disc	

Control Format

The control format belongs to the computer-controlled electric servo format.

The control signal for each axis obtained by the main computer (LSI-11) in real-time computation is distributed to each axis control circuit, consisting of a microcomputer, a PROM, and a RAM through a microprocessor I/F. The action of each axis is then controlled by an analog servo driven by the control signal via a D/A converter. The following five control modes are available:

1) Free control: each axis can be moved manually.
2) Independent control of each axis: each axis can be moved independently.
3) Absolute coordinate control: the tip of the wrist moves in the XYZ coordinate system.
4) Wrist system control: the tip of the wrist moves in the wrist (work) coordinate system.
5) Program control: movement is controlled by the user program.

In the PUMA robot system, the position information that is, the position of the hand flange, is stored in the memory in the form of either converted value or displacement value with respect to each axis. To provide the robot with a large amount of position information, a relative designation format can be used (when a reference position exists, the name of the new position to be designated can be separated from the name of the reference position by a colon :). If the reference position is changed, all other position information designated relative to it changes automatically. Therefore, it is relatively easy to deal with a situation involving a change in arrangement of the work object. Moreover, if the wrist coordinate system is employed, a new hand's dimensional data need not be designated even after the hand is replaced by a new hand with a different shape. A new wrist vector matching the new shape will be designated by VAL.

External Signal Connection

The control device of this system is connected with the external equipment by the following input/output signal lines.

1) Input signal usable by VAL (8 circuits).
2) Output signal usable by VAL (8 circuits).
3) Input signal with special function.

Moreover, since the input/output circuit signals are on TTL level (Figure 6), it is necessary to amplify the signals in order to be able to drive the relay and to insulate or isolate the system in order to eliminate noise and to protect the circuit. Therefore a photocoupler is used to isolate the system from the external circuit, and the signals to drive relays and the relay output signal are transmitted via this coupler.

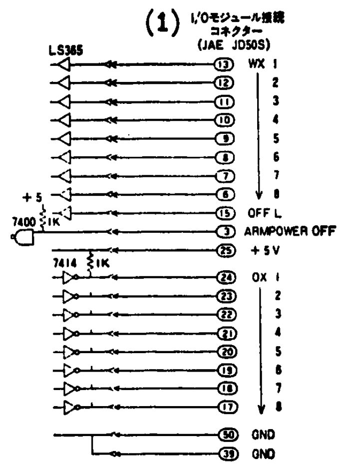


Figure 6. Input/Output Circuit Diagram

Key: (1) I/O module connecting connector

Program Language VAL

VAL is a language developed especially for control of the robot. The robot can be controlled accurately and easily through the use of this language.

Using the program language VAL, the user can write his program describing the robot movement (commands to robot consist of simple words and numbers).

VAL has many functions, including: 1) function to control the robot movement, 2) function to edit the program written by the user and to execute it, 3) function to maintain surveillance over the robot status, 4) function to accept information transmitted from various sensors including vision system, and 5) function to control complicated robot movement in conjunction with other control functions such as continuous path control (for example, weaving of robot body). It is also capable of editing program while the robot is in operation. It is capable of using subroutines written in FORTRAN. Thus, complicated operations can be programmed easily.

The robot system can be tested through the use of monitor command. By doing so, a number of parameters stored inside VAL can also be modified (this command will not be executed while the program is running).

Conclusion:

Although the description is brief because of space limitation, I would like to add the following in closing: the PUMA series robots resemble the human arm in shape and degrees of freedom, and unlike conventional industrial robots, receive operation instructions in special robot language. Making the most of its outstanding features, including compactness, high speed, and high precision, these robots can perform arc-welding on a complicated curved surface, painting operation requiring high-speed track control and speed control, inspection and measurement, to say nothing of various types of assembly work. The PUMA series robots are expected to play an active role in various types of handling operations for some time to come.

Toshiba Steel's TOSMAN-300

Tokyo DENSHI GIJUTSU in Japanese Vol 24 No 1, Jan 82 pp 57-60

[Article by Nobuo Taguchi, director of Robot Department, Toshiba Steel: "TOSMAN-300 Robot System"]

[Text] A general-purpose advanced robot, IX-15, of polar coordinate type comes to mind when spot-welding of automobiles is mentioned. The technical know-how related to the spot-welding robot used for automobile body construction accumulated over the years has been expanded, and a new TOSMAN T-300 series has been developed and put into operation.

The T-300 series is a multiple-arm robot system capable of carrying out a number of welding operations simultaneously. Its construction employs the building block format. It can control a maximum of eight robots having three AC servo axes and one ON-OFF axis.

The characteristics of the T-300 are as follows:

1) Easy to organize by the user.

Since the building block format is employed, the user can choose as many axes as he wants according to the work object and the welding location, and organize his robot system economically.

2) Versatile installation attitude: vertical, horizontal, or oblique.

The robot may be installed in parallel, in perpendicular, or slanted with respect to the work object. It can even be installed suspended from ceiling, or changed from right-hand to left-hand arrangement and vice-versa.

3) Capable of controlling a maximum of eight robots.

Using a microcomputer, the control device of the T-300 is capable of simultaneously controlling a maximum of eight robots. Therefore, even if the line tact is rapid, a large number of welding operations can be carried out simultaneously by properly distributing the work to each individual robot.

4) Large memory capacity and high reliability.

The microcomputer contained inside the control device processes the data and controls eight robots using time-sharing format and handling a series of sequences by DDC format. All of this is handled by the software. The program uses 192 points for each robot, and six different types of operation can be programmed.

5) Easy maintenance through use of electric motor.

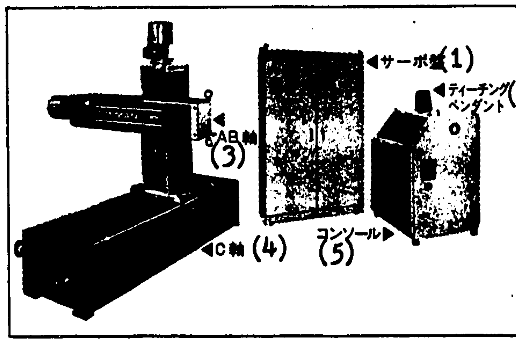
Positioning of the direct translation axis is accomplished by an AC motor, so the reliability is high and maintenance is simple.

System Construction

The basic specifications and the external appearance of the T-300 are shown in Table 1 and Photograph 1, respectively. The system consists of a maximum of 8 robot bodies, 24 axes plus 8 ON-OFF axes, a console panel containing a microcomputer, a servo panel to drive the main body motor, and a teaching pendant. The system construction diagram is shown in Figure 1.

Table 1. Basic Specifications of TOSMAN-300

Mechanical specifications		
Degree of freedom	Each robot can assume the following construction 1) A-axis or B-axis; single-axis construction. 2) A-axis and B-axis; 2-axis construction. 3) A-axis or B-axis and θ-axis; 2-axis construction. 4) A-axis, B-axis, and θaxis; 3-axis construction. 5) Combination of 1)-4) and C-axis.	
Action range and speed	Action range	Maximum positioning speed
1) A axis	200/400/600 (mm)	90 mm/sec
2) B axis	200/400/600 (mm)	90 mm/sec
3) C axis	600/900/1200 mm	120 mm/sec
4) θ axis	60°	20°/sec
Load capacity	20 kg (at a distance 300 mm from wrist center)	
Repeated position reproduction accuracy	±1.5 mm/axis (C axis down direction ±2.5 mm)	
Control specifications		
Control format	Controls a maximum of 8 robots simultaneously	
Positioning path	PTP (point to point)	
Memory capacity	Fixed allocation: 192 points per robot (1,536 pts max)	
Car model selection	6 car models (32 points per car model)	
External signal	1) Interlock signal: input/output, 2 each/robot 2) Car model detection signal: 6 kinds, 4 stages 3) Welding signal 4) Stop signal	
Input electric power	AC 200/220 V ±10 percent 3ϕ 50/60 Hz	
Ambient temperature	0-40°C	



Photograph 1. External Appearance of T-300

Key:
(1) Servo panel
(2) Teaching pendant
(3) A and B axes
(4) C axis
(5) Console

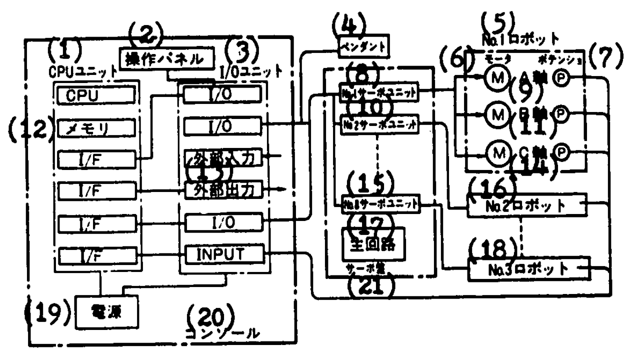


Figure 1. T-300 System Construction Diagram

Key:
(1) CPU unit
(2) Operation panel
(3) I/O unit
(4) Pendant
(5) No 1 robot
(6) Motor
(7) Potentiometer
(8) No 1 servo unit
(9) A axis
(10) No 2 servo
(11) B axis
(12) Memory
(13) External input
(14) C axis
(15) No 8 servo unit
(16) No 2 robot
(17) Main circuit
(18) No 3 robot
(19) Power source
(20) Console
(21) Servo board

The console panel consists of a power source, a microcomputer unit, I/O units, and an operation panel. It is capable of controlling a maximum of eight robots. Eight sets of switches controlling various power sources, main circuit operation unit, and servo units to drive each axis motor are contained inside the console panel. The servo units may be added to or removed from the console according to the actual number of robots used. The teaching pendant may be used to operate any one of the eight robots by a selector switch on the console. However, during the repeat mode, all eight robots will operate simultaneously. A signal indicating completion of the work will be issued to the outside only after the work operations of all eight robots are completed, and the system will then take up the next operation. The mechanism unit consists of a pole-change motor, a feed screw, a detector, and a film potentiometer.

The position information and the control information are stored in an IC memory with battery backup.

Control of the three AC-servo axes employs an ON-OFF servo format. That is, the value obtained by the position sensor and the value read from the data are compared, and if the difference between these two values comes to within a designated deviation range, a stop command is issued to the driver unit to halt.

Control System

Figure 2 gives the outline of the control system.

The control console may be roughly divided into two parts: a computer unit containing a microcomputer and an I/O unit handling the external input/output signals. The CPU card consists of a Toshiba 16-bit high speed microprocessor and an IC memory with battery backup as its memory, together with an 8 kW CMOS RAM and an 8 kW EPROM. While each I/O interface baseboard inside the computer unit is controlled by the CPU (processed by the software), the interface baseboard in the I/O unit receives logic level signals and its output is used to drive the relays or mercury relays.

After passing through a filter, the input from the potentiometer is subjected to an A/D conversion and then managed by the CPU; the so-called digital processing (DDC) format is used. The control formats used during the teaching and repeat periods will be described next.

1. Teaching Action

The A, B, and C axes are driven by the hardware during the teaching period without the help of the CPU.

By pressing a push-button switch on the teaching pendant corresponding to either A, B, or C axis, a drive command can be entered through the hardware to the corresponding axis output interface, which activates the mercury switch on the mercury relay driver, which in turn activates the contact inside the servo unit which drives the motor. Therefore, this mode can also be used as a manual mode.

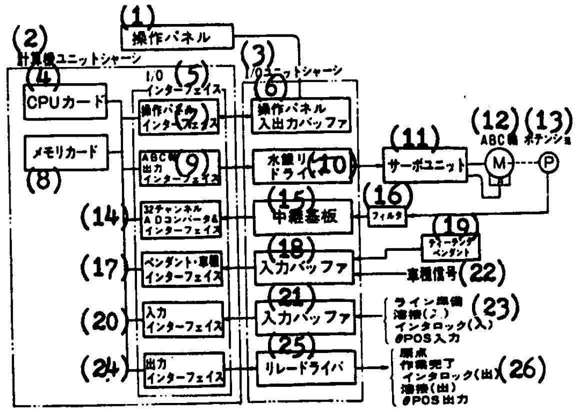
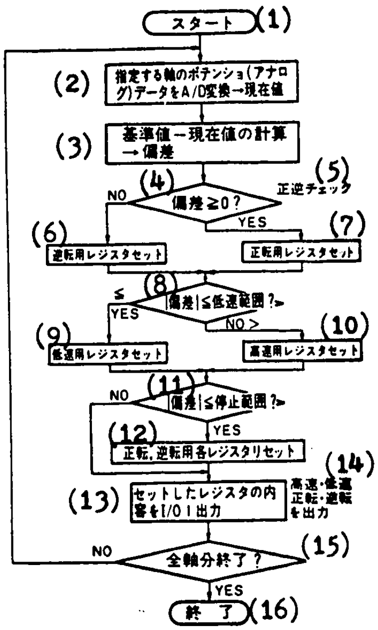


Figure 2. Control Outline Diagram

Key:
(1) Operation panel
(2) Computer unit chassis
(3) I/O unit chassis
(4) CPU card
(5) I/O interface
(6) Operation panel input/output buffer
(7) Operation panel interface
(8) Memory card
(9) ABC axes output interface
(10) Mercury relay driver
(11) Servo unit
(12) ABC axes
(13) Potentiometer
(14) 32-channel A/D converter and interface
(15) Relay baseboard
(16) Filter
(17) Pendant-car model interface
(18) Input buffer
(19) Teaching pendant
(20) Input interface
(21) Input buffer
(22) Car model signal
(23) Line preparation, welding (input), interlock (input), θ POS input
(24) Output interface
(25) Relay driver
(26) Origin, work completion, interlock (output), welding (output), θ POS output

After the robot is moved to the desired position, the control information switches on the operation panel and the pendant are set and the memory push button is pressed. By this action, the position information in the form of potentiometer input is subjected to A/D conversion and accepted by the CPU as control data. Inside the CPU, the position information and the control information are stored in a memory address designated for that particular robot.

This teaching process is repeated until the teaching of all eight robots is completed.



(1) Start

(2) A/D conversion of potentiometer (analog) data of a designated axis--present value

(3) Reference value--present value--deviation

(4) Deviation ≧ 0?

(5) Positive-negative check

(6) Reverse drive register set

(7) Forward drive register set

(8) |Deviation| ≦ low speed range?

(9) Low speed register set

(10) High speed register set

(11) |Deviation| ≦ stop range?

(12) Forward and reverse drive register sets reset

(13) Output of content of the register set

(14) Output high or low speed, forward or reverse drive

(15) All axes completed?

(16) Complete

Figure 3. Time-Sharing Processing Program

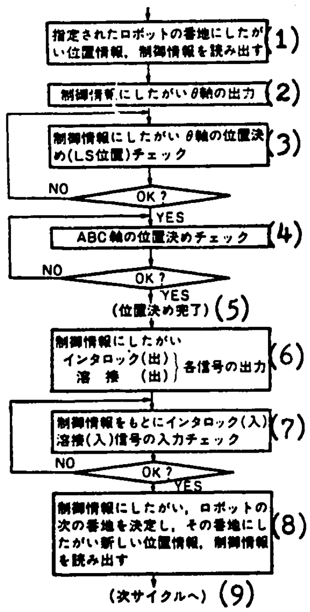
2. Repeat Action

During the repeat period, the information concerning both control and position contained in the memory address corresponding to each of the eight robots is first read into the working RAM. The information related to the A, B, and C axes drive is processed by a time-sharing processing program according to the time allocated by the system clock.

Figure 3 provides a flow chart of the time-sharing processing program. According to the time-sharing processing program, the analog data obtained from potentiometers located at various axes of each robot are subjected to A/D conversion and the digital data (the present value) thus obtained is compared with the position information (the reference value) read into the working RAM. Based on the result of this computation, a command will be issued through I/O to effect the changes, such as forward or reverse rotation and higher or lower speed. This operation is repeated for all axes of the eight robots. This operation is carried out in DDC format with sampling.

Figure 4 illustrates the action flow chart during the repeat period.

The main program manages the results obtained from the time-sharing processing program. It checks whether the deviation (reference value minus present value) is within the positioning range or not. If so, it confirms the positioning. As to the ON-OFF axis (the θ axis) used on the wrist, the main program



(1) Read position and control informations at the address of designed robot.

(2) θ axis output according to control information

(3) Check θ axis positioning (LS position) according to the control information

(4) Check ABC axes positioning.

(5) Positioning complete

(6) Output interlock and welding (output) signals according to control information

(7) Check interlock and welding (input) signals according to control information

(8) Read new position and control informations at the new address of the next robot according to control information.

(9) Next cycle.

Figure 4. Flow Chart for Repeat Period

processes the output according to the control information and also checks its positioning.

After positioning of all axes (A, B, C and θ) is completed, the CPU will decide what is to be done next based on the control information. That is, it will issue appropriate signals to I/O as needed to check the external interlock signal and the welding signal input/output.

This cycle is repeated for the next point by reading the pertinent information from the memory.

Method of Operation

A maximum of eight robots can be controlled simultaneously by the T-300. These eight robots may be concentrated at one station, or distributed over several stations. Take the case in which there are two robots each at four stations, for example. The work objects being welded at these four stations may be the same or different (car model, for example). As the work flows along the line, after completion of each welding task, the car model signal for the new work must be read. Therefore, the repeat operation consists of four modes: step operation, cycle operation, process cycle operation, and automatic operation. These four modes of operation are briefly described below.

1. Step Operation

One of the eight robots is chosen and the addresses with identifying numbers are visited one after another by pressing the pushbutton. If the car model signal supplied from outside is present, then the action of the robot is determined by this signal. That is, the control passes to that address corresponding to the car model.

2. Cycle Operation

Like the step operation described above, one work cycle of a selected robot is carried out automatically.

3. Process Cycle Operation

This refers to the stage operation of the eight robots. Cycle operation is carried out in a stage group selected from among one-six stages.

4. Automatic Operation

In principle, each robot starts operation corresponding to its car model. Robots belonging to each stage group start operation upon receipt of a signal indicating the preparation is completed. Those robots which complete the operation sooner than others will wait until all the robots complete the operation. When the operations of all the robots are completed, a signal is issued to the line and preparation for receiving new work begins.

Thus, 192 numbered memory addresses for each robot can be divided and distributed among various car model signals. Figure 5 illustrates the assignment of addresses among six different car models. It is evident from this drawing that the address 0 is the origin common to all car models.

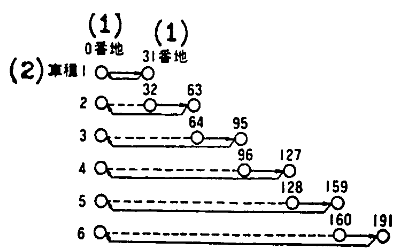


Figure 5. Allocation of Addresses According to Car Model

Key: (1) Address number (2) Car model

Example of Application

When robots are used for spot-welding an automobile body, selection of the robot becomes very important depending upon the line tact. For example, when a cycle time longer than 1 minute is allowed for a robot with a six-axis polar coordinate system, the number of welding points may be in the range of 30-50, and the six-axis characteristics can be fully utilized. However, if the cycle time is of the order of only 30 seconds, then the number of welding points will be in the range of 15-25, and there will be no need for the six-axis system. Therefore, it becomes more cost- and performance-effective to carry out the welding operation using a number of simple robots with three-axis construction, such as the T-300 arranged three-dimensionally.

Figure 6 illustrates a suspended, vertically installed T-300 system. There are three robots at this station. With these three robots, 39 spot-weldings are carried out with a robot cycle time of 32 seconds. Therefore, this arrangement is clearly less costly than the use of two robots with a polar coordinate system. The control console and servo panel are located at a station where they are easy to operate.

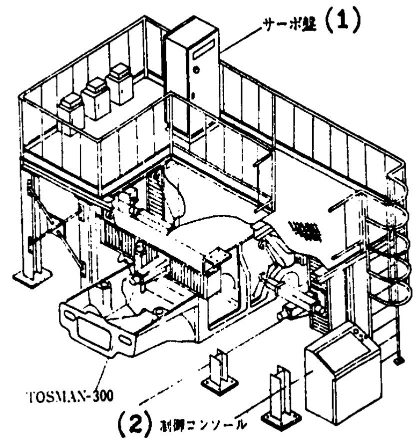


Figure 6. Example of T-300 installation

Key: (1) Servo panel (2) Control console

Conclusion

A group control format for robot control was explained with the TOSMAN T-300 control system as an example. Simultaneous control of eight robots is a control format suitable for large manufacturers which engage in mass production of medium variety. This format is not as suitable for an operation in which only one station is required. Concentrating eight robots at one station often poses space problem as well as maintenance problems. Therefore, the T-300 system is also equipped with other control formats such as control of two units and sequential control of each axis. We also have robots of the T-200 series, a sister series, consisting of two-axis construction.

Robot control technology must continue to develop and evolve. This company is also undertaking T&D of a robot system capable of dealing with a flexible manufacturing system.

Sankyo Seiki's SKILAM

Tokyo DENSHI GIJUTSU in Japanese Vol 24 No 1, Jan 82 pp 61-64

[Article by Yukio Oguchi, director of Industrial Machinery Business Development Office, Sankyo Seiki Manufacturing: "SKILAM's Control System"]

[Text] Outline of SKILAM Assembly Robot

This robot is a multiple-jointed robot with three axes + one axis control, developed especially for the assembly work. The assembly robot has just reached the practical application stage, and it appears that some time will be needed before the perfect robot will appear because so many control elements are involved. Meanwhile, SKILAM as a general-purpose robot equipped with all basic elements necessary for assembly work seems to point to the future trend. Although its construction is very simple, it has a wide range of applications thanks to its improved manipulators and intelligence.

Photograph 1 shows the robot body of Model SR 3, Figure 1 gives its construction diagram, and Figure 2 shows its working area. Its θ1 axis (first joint) and θ2 axis (second joint) are driven by DC servomotors. The tip can be positioned at any point inside the working area by controlling these two angles. The S axis at the tip can be rotated ±180° by a stepping motor, and the attitude of the tool attached to the tip can be controlled. The three axes referred to above are simultaneously controlled numerically. Also, there is an additional axis (air cylinder) called the B axis, which provides up-and-down motion of the S axis. SKILAM can be used on a wide range of applications, including inserting, pressing, boxing, and soldering small parts.

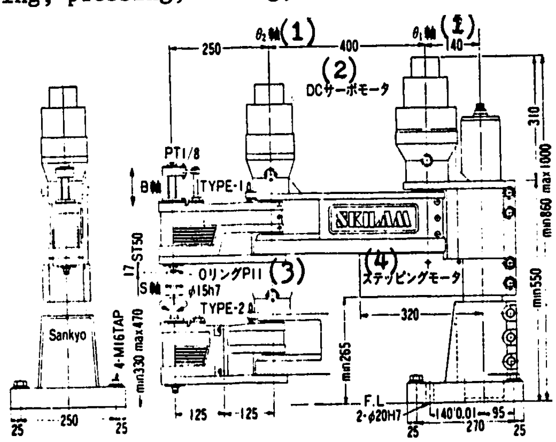


Figure 1. Robot Mechanism Diagram

Key: (1) Axis
(2) DC servomotor
(3) O ring PII
(4) Stepping motor

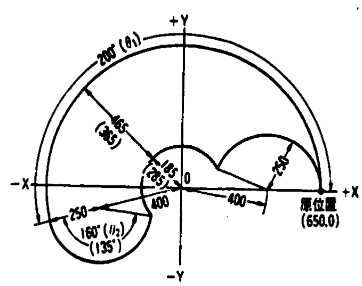
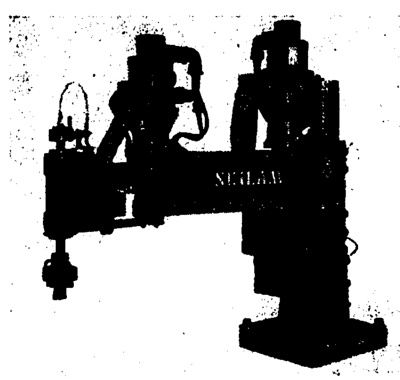
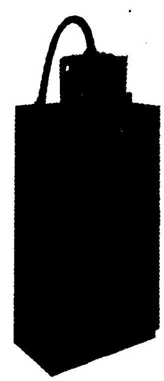


Figure 2. Working Area





Photograph 1. Robot Body

Photograph 2. Control and Operation Box

Electrical Specifications

An outline of its electrical specifications is summarized in Table 1 and its control and operation console are shown in Photograph 2. The following conditions were taken into consideration during its design as the conditions necessary from the viewpoint of controlling the assembly robot.

1) Its cost must be able to compete with the personnel expenditures.
2) Its operation control must be simple enough so it can be manned by workers.
3) Since it is often used in conjunction with other automatic machines, it must be able to exchange signals easily with its peripheral equipment.

Table 1. Electrical Specifications

Control format	Servo control by microprocessor and synchronous control of peripheral equipment
Action format	PTP (point-to-point) format
Position detection	Rotary encoder; S axis is by stepping motor without encoder
Data memory format	CMOS-RAM with battery backup
Data memory capacity	400 points (may be divided into 5 types of variable lengths)
Control axis number	3 axes simultaneous control + 1 axis (B axis)
External input signal	16 points (user-released, LED display)
External output signal	16 points (user-released, relay contact output)
Setting unit	θ_1 and θ_2 axes: 0.01 mm; S axis: 0.01°
Teaching	XY coordinate input format using robot language (SERF) (program unit is of separate type, separate estimation)
Data format	Absolute
CPU	Z 80
Offset function (coordinate modification	X,Y--max ±9.99 mm, S axis--max ±3.15° θ axis--max ±9.99 mm
Point determination and modification function by learning	X, Y rectangular coordinates and S axis
Sequencer	SPLC2 (Sankyo product)
Power source	AC100V ±5 percent, 1 KVA
Speed control	Cam curve (NC 2 curve)

4) It should not have special sensors of its own, but must allow connection of sensors provided by the users.
5) In order to widen the range of general application, a robot language must be employed so that its intelligence level can be improved through upgrading its software.

Control Box Construction

This machine was designed to be installed on an assembly production line, so the operation box is placed in front of the operator while the control box is installed separately behind the production line for better work efficiency. For the sake of economy, the control box does not have any unessential decorative element. The operation at the operation panel follows the operational format of conventional machine tools in order to eliminate the image of numerical control--that is, the operator does not handle numbers directly.

The special program unit is of a separate type, so only one unit is needed to control several robots. Programs can be prepared according to need and then loaded onto the unit.

Control System

Figure 3 shows the block diagram of the control system. The CPU, consisting of a Z 80, is connected with the program unit by an RS 232C. The user program written in robot language is loaded onto a 6-kilobit CMOS memory with battery backup. The user programs, which are of variable lengths, are divided into five types and stored. Any single program may be selected by the touch of a button on the operation panel. Functional computation is carried out by an APU (AM 9511) for the sake of high speed. It is also equipped with a CRTC, so maintenance monitoring can be accomplished by simply connecting a CRT display to it.

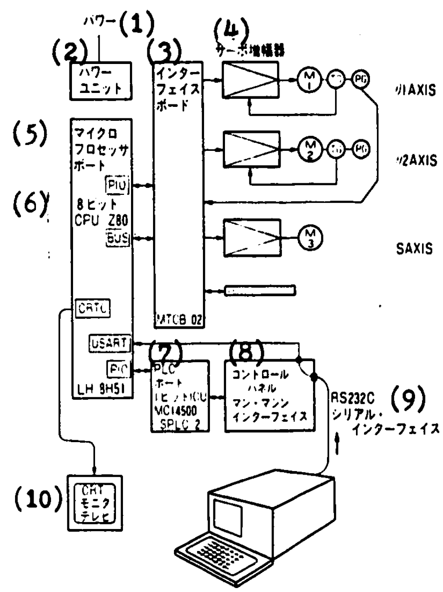
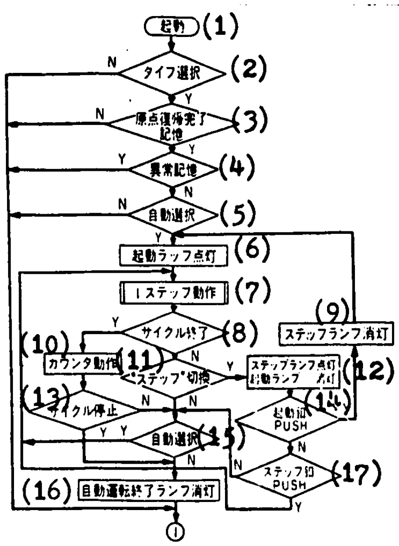


Figure 3. Block Diagram

Key:

(1) Power
(2) Power unit
(3) Interface board
(4) Servo amplifier
(5) Microprocessor board
(6) 8-bit CPU
(7) PLC board 1-bit ICU
(8) Control panel man-machine interface
(9) RS 232C serial interface
(10) CRT monitor TV

One of the special features of this machine is the fact that a sequencer (homemade) is used as the main controller. The 8-bit CPU merely executes the subroutines designated by the command issued by the sequencer. Figure 4 shows an example of a flow chart. In this example, the job for the Z 80 is confined



(1) Start
(2) Type selection
(3) Return to origin completed, memory
(4) Abnormality memory
(5) Automatic selection
(6) Start lamp on
(7) One-step action
(8) Cycle completed
(9) Step lamp off
(10) Counter action
(11) Step switching
(12) Step lamp on, start lamp off
(13) Cycle stop
(14) Start button PUSH
(15) Automatic selection
(16) Automatic operation complete lamp off
(17) Step button PUSH

Figure 4. An Example of Execution Flow Diagram

to a "one-step action" processed according to a subroutine. The sequencer and the Z 80 are joined by a 16-bit board. The advantages of using a sequencer (1-bit CPU) as the main controller are as follows:

1) The time required to develop a software for the sequencer is much shorter than that required for an 8-bit CPU.
2) Software change can be accomplished very easily, so it can readily deal with system changes.
3) Real-time processing can be carried out without the use of complicated time-sharing processing, so the problem related to operational interlock can be easily and surely dealt with. Peripheral parallel multiple processing is also possible.
4) The control signal can be treated as a single wire signal instead of a code, because of the 1-bit structure.
5) The system reliability is improved, because it is highly resistant to noise.
6) The load on the 8-bit CPU can be reduced.

Characteristics of the Servo System

Generally speaking, when a motor is accelerated or decelerated, the speed reducer will experience a sudden change in acceleration and a mechanical shock resulting from it. To soften this mechanical shock and to increase the durability of the mechanical members, the acceleration is controlled and kept below a certain fixed value. Acceleration and deceleration of the arm are controlled so that its velocity change follows a special cam curve. This cam curve consists of the NC 2 curve developed by Professor Makino of Yamanashi University.

The method of control goes as follows: A locus is calculated in advance and stored in the ROM as the bit image. Using this as the basic pattern, the arm velocity is automatically varied according to the selected velocity. Figure 5 gives actually measured data. As a result, smooth acceleration and deceleration are achieved through use of the NC 2 curve and there is no overshoot in locating a point. Thus, improved mechanical accuracy is achieved, and at the same time the maximum speed can be raised to the mechanical limit without inducing undue stress in the member. Having its own hardware, the feedback system not only lessens the load on the CPU but also produces accurate computational results as fast as the arm can move, because of its high processing speed.

User I/O

It is equipped with an open user terminal consisting of 16 input points and 16 output points. Input/output can be controlled by the robot language used on the program unit. Its input is not isolated. The noise control countermeasures include input impedance treatment, ground treatment, and software treatment. No-voltage contact and a sensor with open collector output may be connected to the input. The output is equipped with 16 control relays and may be user-released to be used as no-voltage contact. Therfore, a load having a different voltage can also be controlled directly.

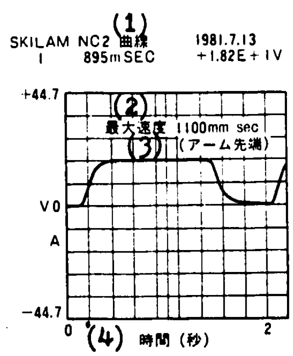


Figure 5. The NC 2 Curve

Key: (1) Curve
(2) Maximum speed
(3) (Arm tip)
(4) Time (second

Self-Diagnostic Functions and Memory Protection

The newest software (level 2) used on this machine is capable of self-diagnosis and maintenance monitoring. By simply connecting a monitor TV to the unit, the results of self-diagnosis and error messages can be displayed on the TV screen. It also enables the operator to maintain surveillance of the input status, the content of transferred data, the name of the user program, and the conditions during an automatic operation period. Time-sharing processing is employed to achieve this. Development of the software is being undertaken in order to further improve the self-diagnostic functions. Since a CMOS memory with battery backup is used for the storage of the user program, the reliability of the memory in keeping the data content can be somewhat of a problem.

However, this machine is equipped with an independent power-failure detection unit which can not only prevent the CPU from running away at the time of power failure but also protect the CMOS memory.

Programming Unit

The Model SRP-10 programming unit and its keyboard arrangement diagram are shown in Photograph 3 and Figure 6, respectively. This unit has a standard construction centered around an 8-bit CPU, 6800, and assumes a portable terminal format. The user program is written in the robot language SERF (Sankyo Easy Robotic Formula) by a special sheet keyboard. The program is translated into an intermediate language before it is loaded onto the robot. Software is centered around an editor and consists of syntax processing, translation into intermediate language, and control or peripheral devices. Figure 7 gives an example of a program written in robot language as part of the newest software (level 2). The program allows a conditional jump according to the input. The details of SERF will be omitted. The unit is also equipped with a printer by which a hardcopy of the list can be produced. The auxiliary memory unit utilizes a data cartridge recorder (manufactured by Sankyo) for the convenience of on-site application. A single cartridge can hold 32 different types of user programs.

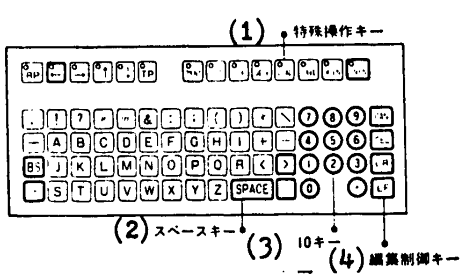
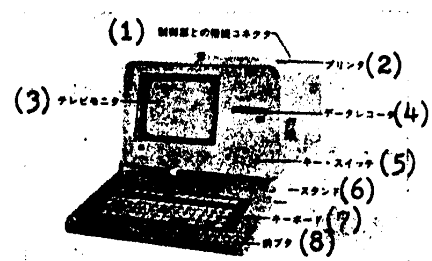


Figure 6. Key Arrangement

Key:
(1) Special operation key
(2) Space key
(3) IO key
(4) Editing control key



Photograph 3. Program Unit

Key: (1) Connector to be connected with control unit
(2) Printer
(3) TV monitor
(4) Data recorder
(5) Key switch
(6) Stand
(7) Keyboard
(8) Front cover

In robot language, the position data list is constructed by entering the data in the form of absolute values of X-Y coordinates. It is also equipped with a mode of operation in which direct operational commands may be entered. While the robot is connected, positioning in the X-Y coordinate system can be accomplished by the key command using a method similar to an ordinary mimic function, and the coordinate values of the point may be either read or printed out.

Upgrading software

Numerous revisions of software have been made since SKILAM was first put on the market. Roughly divided, there are three levels to the software according to the plan. The software is at the level 2 stage today. When the final level, level 3, is reached, the robot is expected to become an intelligent robot loaded with a considerable number of functions. The robot performance is to be upgraded through change in the software without significant changes in the hardware. Each time the software is upgraded, it is made known to the users, and the software is exchanged if requested.

We intend to keep on developing the software in the future with input from the user so the intelligence of the robot can be raised steadily.

```
NAME IF-TEST
TYPE L
P1=458,458,180
P2=0,650,-180
P3=-132,132,180
P4=-126,-137,-180
P5=650,0
S1=L1(ON),I1(ON),L2(ON),L1(OF),I
2(ON)
S2=L1(ON),I1(ON),L2(OF),L1(OF),I
2(ON)
S3=DLY(1.0)
1 HOME
IF I3=ON GO 10
DO/1,PI,P1,P2
MV/P5,S1,PI,S2
NE/1
IF I4=ON GO 30
GO 1
10 DO/2,PI,P3,P4
MV/P5,S1,PI,S2
NE/2
GO 1
30 END
```

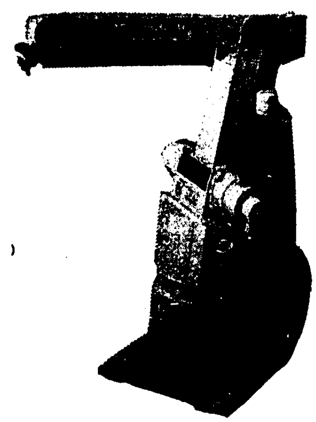
Figure 7. An Example of Robot Program

Yasukawa Electric's 'Motoman'

Tokyo DENSHI GIJUTSU in Japanese Vol 24 No 1, Jan 82 pp 65-68

[Article by Seiji Horikawa, NC Design Division, Tokyo plant, Yasukawa Electric Manufacturing: "Motoman and Its Control System"]

[Text] The world's first microcomputer industrial robot was put on market by this company in 1974 using an "IMP 16" microcomputer which had appeared not long before. A high-performance industrial robot can be realized only as a result of successful unification of machine and electronics, as symbolized by the term "mechatronics." Since the first microcomputer industrial robot was manufactured, we have engaged consistently in the development of arc-welding robots, constantly adopting ever superior microcomputers. The know-how related to both software and hardware concerning robots and arc-welding accumulated over the years culminated in the completion of Motoman today. The demand for Motoman in the field of arc-welding has been very favorable, so its monthly production has reached 80. Its reliability, economy, and high performance have been highly appraised, and it was recognized by the 1981 Machinery Promotion Society award (see Photograph 1).



Photograph 1. Motoman L 3

Photograph 2. YASNAC 6000 RG

The "YASNAC 6000 RG," which is to be introduced here, is the control device for Motoman. It is a product resulting from a concentration of this company's control technologies. Its outstanding features will be described below.

Development Concept of YASNAC 6000 RG

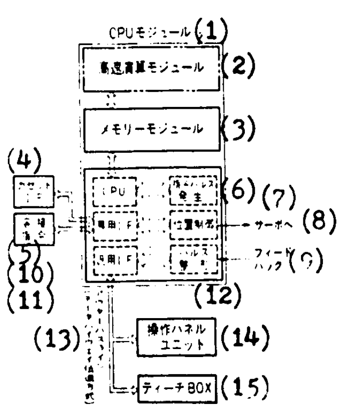
The industrial robot market became highly diversified as the robot became more and more popular, and demand for a robot system with higher flexibility became greater. Moreover, much is expected of the robot as production equipment which is to improve productivity, so what an industrial robot should be must not be confined to the viewpoint of a robot single body system but rather considered from the viewpoint of being a member of a consolidated system in a future production line.

For example, group management of FMS (flexible manufacturing system) and implementing systematization of the robot, among other production facilities (see Photograph 2).

At first, the industrial robot was considered suitable for small production of a large variety of products exclusively. Recently, the robot has also been found suitable for mass production of a small variety of products, and a large number of robots are being introduced to various types of production lines, while even stricter demands are placed on its cost, reliability, and maintainability.

With this background, the basic development concept for our new control system consisted of the following five specific improvements over the conventional control systems:

1) Greater system flexibility.
2) Significant improvement in functions to meet the needs.
3) Consolidation of self-diagnostic function and improvement of protective function of the system.
4) Improvement in reliability and maintainability.
5) Simplified construction for mass production (see Figure 1).



Key:
(1) CPU module
(2) High-speed computation module
(3) Memory module
(4) Cassette I/F
(5) Welding command
(6) Command pulse generation
(7) Position control
(8) To servo
(9) Feedback
(10) Special I/F
(11) General purpose I/F
(12) Pulse shaping
(13) Outer bus line (data highway transmission format)
(14) Operation panel unit
(15) Teach box

Figure 1. Block Diagram of YASNAC 6000 RG Control

System Flexibility

A standard Motoman uses simultaneous five-axis control, but YASNAC is capable of simultaneous six-axis control. The system is designed with sufficient margins in such areas as memory capacity and the number of IN/OUT channels for system expansion and diversification.

Improved Functions

Its main functions may be summarized as follows:

1) Memory capacity(number of teaching points: 1,000).
2) Larger number of analog commands for welding machine (4 channels).
3) Improved transistor servodrive.
4) Consolidationof runaway detection function.
5) Addition of three-dimensional high-speed computing unit.
6) Addition of cumulative work hour counting capability.

These results are achieved through concentration of both hardware and software technologies.

Among these special features of YASNAC, the transistor servodrive among the three-dimensional computing unit will be described concretely.

1. Transistor PWM Type Servodrive

From the beginning, YASNAC adopted a servodrive system using "transistor PWM format" and thus achieved superior performance. Servodrive is one of the most important elements of a robot; it has direct influence on the accuracy of positioning and the accuracy of interpolation (see Figure 2).

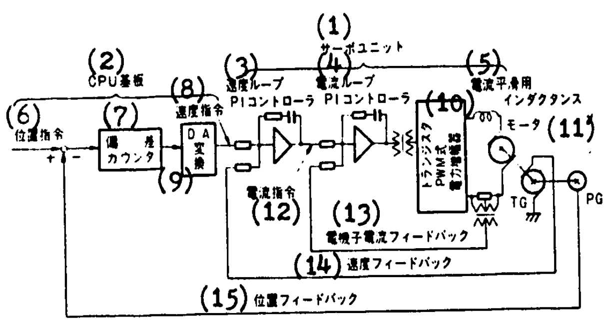


Figure 2. Block Diagram of Digital Servo System

Key:
(1) Servo unit
(2) CPU baseboard
(3) Speed loop PI controller
(4) Current loop PI controller
(5) Current smoothing inductance
(6) Position command
(7) Deviation counter
(8) Speed command
(9) D/A conversion
(10) Transistor PWM type power amplifier
(11) Motor
(12) Current command
(13) Armature current feedback
(14) Speed feedback
(15) Position feedback

This company is a special maker of servomotors and systems utilizing servomotors. The "CPCR-MR" type servodrive unit installed on board the YASNAC 6000 RG is fully supported by our know-how in the field. The main features of this unit are as follows:

1) Fewer number of parts through use of IC's.
2) Appropriate carrier wavelength for the realization of high efficiency.
3) Consolidated protection function including fuseless main circuit and open-circuit detection for speed detector (TG = tachogenerator).
4) Better heat dissipation and protection from dust for higher reliability.
5) Connectors for signal connection with superior maintainability.

Servodrives used in many robots employ "thyristor" drive. The two types of drives will be compared briefly.

While a carrier having a frequency ranging from several hundred Hz to several kHz regenerated from direct current is used in the transistor PWM type drive used in YASNAC, the thyristor drive uses a carrier having the same frequency as the power source. As a result, significant differences exist not only in the control performances of the two, but also in matters related to maintainability. Because while the thyristor drive is directly affected by the source voltage, the source frequency, the source waveform, and the phase sequence, the transistor PWM type device can maintain high-control performance completely unaffected by the power source.

The fact that there is no need for servo adjustment when the Motoman is set up and that stable performance can be maintained over an extended period are due largely to the transistor PWM type drive.

2. Three-Dimensional High-Speed Computing Unit

A high-speed computing unit using a high-speed microcomputer was developed for the purpose of simplifying the robot teaching operation. As a result, a multiple-jointed Motoman robot can be taught via the rectangular coordinates system, and the advantage of multiple-jointed robot functions are added to the superior operability of a rectangular coordinates robot. Furthermore, the following features are realized in YASNAC through a combination of this high-speed computer unit and the know-how of this company concerning industrial robots.

1) Three-dimensional linear and arc interpolation function: it is capable of carrying out linear interpolation through two-point teaching and arc interpolation through three-point teaching in three-dimensional space.

2) Three-dimensional shift function: for work items of the same shape, it is necessary to teach just once, and the rest can be simply copied. Moreover, if the work position has shifted, the teaching data can be revised completely by merely reteaching three points.

3) Three-dimensional mirror image function: for a work item with left and right symmetry, the teaching data of one side can be easily converted by means of an inversion.

4) Three-dimensional scaling (enlargement and reduction) function: the teaching locus can be enlarged or reduced in size. This function demonstrates its power when it is applied to multiple layer welding of a heavy plate.

5) Three-dimensional soft-weaving function: weaving for heavy plate welding can be accomplished in three-dimensional space.

6) Real-time arc sensing function: even when the welding line and the teaching locus become misaligned as a result of thermal strain, the locus can be revised automatically through sensing of the welding conditions, and the welding operation can be carried out under optimum conditions.

Self-Diagnosis Function

With YASNAC, the movements of various parts are all controlled by microcomputer commands, so it is relatively easy to maintain surveillance of the state of movement and to make a diagnosis. The self-diagnosis function can be readily divided into two groups: on-line (real-time) and off-line.

The on-line self-diagnosis is a function built into YASNAC. This function is continuously at work during the operation of the robot. It maintains surveillance of an abnormal state and the status of input/output signals, and displays these conditions on the CRT. Table 1 contains some examples of the alarm codes. There are approximately 50 additional alarm codes.

The off-line self-diagnosis consists of a separately prepared diagnostic program which can be temporarily loaded onto YASNAC to carry out diagnosis of the system while the robot is not operating. This function is highly useful for in-house quality control and reliability test. It also helps to accomplish a quick recovery from a breakdown once it takes place.

Table 1. Examples of Alarm Codes

11	Abnormal temperature inside panel	31	Servo power source off
16	Offset data destruction	32	Control preparation incomplete
17	Parameter content destruction	33	Emergency stop on
18	Job data content destruction	34	Servo error
21	Soft limit over	35	Overload
22	Origin position bad	36	Feedback error (PG abnormality)
24	Return to origin, begin position bad	38	RPG hardware bad
25	Sequence error	39	Overtravel (overrun LS)
26	Insufficient origin margin	81	CPU abnormality
27	Positioning bad	82	Memory reference error

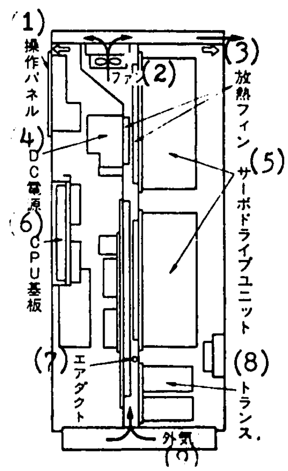
Improvement of Reliability

The environment into which the industrial robots are introduced is usually very bad. This is especially true in case of arc-welding robots. In order to be able to maintain high reliability in such a poor environment, special attention was paid to development of the following three items:

1) Completely dust-proof control panel
2) Reduction in number of parts.
3) Reduction in heat loss inside the panel.

1. Completely Dust-Proof Control Panel

YASNAC realizes a completely dust-proof control panel through the use of a central air dust and an indirect air cooling format. All control panels in which electronic parts are used must employ some form of cooling system in order to maintain a stable operation. High reliability cannot be assured if the control panel of an arc-welding robot is cooled by the air taken from its environment and merely passed through a filter (see Figure 3).



Key:
(1) Operation panel
(2) Fan
(3) Heat dissipation fin
(4) DC power source
(5) Servo drive unit
(6) CPU baseboard
(7) Air duct
(8) Transformer
(9) External air

Figure 3. Completely Dust-Proof Construction of Control panel

2. Reduction in Number of Parts

In order to reduce the number of parts, a custom LSI was adopted in addition to optimizing the circuit design. Six LSI's, each containing several thousands of integrated elements per chip, are used. Although an enormous amount of time and energy is required to develop any LSI, the LSI will remain as one of the most important electronic technologies for the robot industry in achieving miniaturization and high reliability (see Photograph 3).

3. Reduction in Heat Loss Inside the Panel

Heat loss inside the control panel is the main cause of a temperature rise inside the panel and reduction in its reliability. The heat problem must always be contended with as long as the trend is to miniaturize electronic parts. To reduce the heat loss, the following measures were taken during the YASNAC design process.

1) Adoption of IC memory.
2) Overall adoption of IC's with low power consumption.
3) Development of custom LSI.

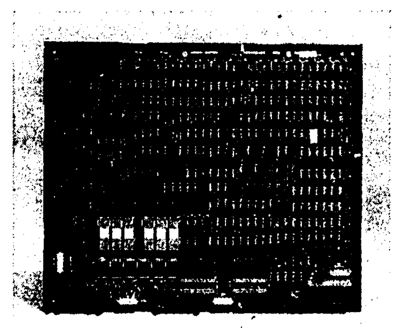
Simple Construction

Simple construction is an important factor that must be taken into consideration if mass production of the control units is contemplated. This also has a strong bearing on the reliability and maintainability mentioned previously. The motto of YASNAC is: "Simple Is Best."

1. One-Board CPU

The main logic unit is contained in a single baseboard (370 x 460 mm). This baseboard contains--in addition to all basic circuits required by robot control, including six axes servo circuit and input/output signal interface--other functions required for testing and maintenance includi[illegible] paper tape reader interface, paper tape punch interface, and DNC interface centered around the microcomputer (see Photograph 4).

Photograph 3. Custom LSI



Photograph 4. CPU Board

A one-board CPU was realized with the aid of custom LSI, a low power consumption IC, and the use of a high-density mounting type multiwire board. The multiwire board is a special wiring board with four layers of wiring planes. The two inner layers are used for supplying power to the mounted parts, while the two outer layers are used for signal wiring. The signal wiring can intersect on the same plane and two wires can be passed between the pins (0.1 inch) of an IC. This wiring board is equivalent to six-eight layers of printed circuit board in mounting density and electric characteristics. The fact that this multiwire board has an excellent antinoise property should also be pointed out (see Figure 4).

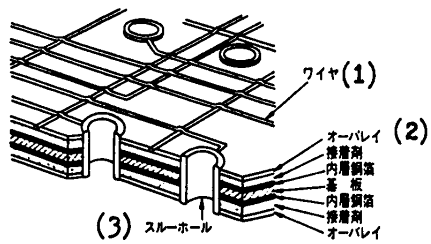


Figure 4. Multiwire Board Structure

Key: (1) Wire (2) (from top to bottom) Overlay, Binder, Copper foil, Baseboard, Copper foil, Binder, Overlay (3) Through hole

2. Various Units With Connectors

A connector connection format was used for all signal wirings. As a result, wire harnessing can be accomplished outside the control panel, and the wiring work has become very simplified as well as separated.

3. Reduction in Number of Signal Lines

To reduce the number of wirings, part of the data transmission is carried out by the high-speed serial data processing unit employing CRCC (cyclic redundancy check character).

Conclusion

The industrial robot, whose market is expanding and whose true value is being assessed on the basis of its impact on both productivity and labor welfare today, demands the most advanced mechatronics technology. The future tasks of us, workers, in the field of electronic technology consists of systematizing various most advanced technologies, including the following:

1) Optic fiber capable of transmitting a large quantity of information at very high speed.
2) High-speed microcomputer for high-speed data processing.
3) Large memory capacity for storing vast amount of software.
4) Sensor for adaptation control.

These technologies will be boldly incorporated into YASNAC, which is the brain of Motoman, so that Motoman may become even more satisfactory to you, the user.

Shinmeiwa Industry's 'Robel J'

Tokyo DENSHI GIJUTSU in Japanese Vol 24 No 1, Jan 82 pp 69-73

[Article by Shigeo Kawabe, chief of Robot Design Division, Takarazuka plant of Machinery Plant Manufacturing Division, Shinmeiwa Industry: "Robel J and Electronics"]

[Text] Greater productivity is demanded of industrial circles in the 1980's. Industrial robots enable small production of a large variety of products, which was difficult to accomplish with the conventional special machine. Industrial robots began to play an important role by becoming the nuclear technology and equipment which enabled automation of various production processes of the 1980's. The robot industry is expected to make big strides as a knowledge-intensive industry.

Development of a general-purpose robot was started by this company in 1969, and a rectangular coordinate system arc-welding special robot was put on the market in 1973. In 1977 large-scale models--PW 150 and PW 200--were made public, and in 1979 the system robot--PW 752 series--was unveiled (see Figure 1).

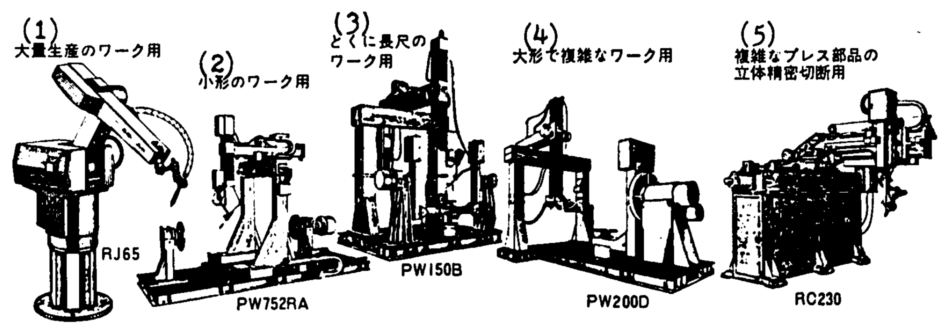


Figure 1. A Group of Robot Products

Key:
(1) For mass production work
(2) For small work
(3) For extra long work
(4) For large and complicated work
(5) For three-dimensional precision shearing of complicated press parts

On the other hand, a shearing robot for cutting plate material was trial manufactured in 1975 and it was put on market this year. We have shearing robots of various types ranging from gas shearing robots to plasma shearing robots (RC 230, made public this year).

We have accumulated know-how in the field of arc-welding and metal-shearing in order to provide robots with high reliability and make them easy to use. The multiple-jointed Robel J type RJ 65 robot, which was made public this year, was developed on the foundation of the know-how accumulated over many years with adoption of the newest mechatronics (see Photograph 1 and Table 1). The special features of this robot include wide action range and simple construction achieved by our own unique design. Software based on a 16-bit microcomputer has been prepared, to make this robot system not only highly reliable but also easy to operate.

Photograph 1. External appearance of Robel J RJ 65

Construction and Action Characteristics of RJ 65

Figure 2 provides the construction diagram. This system consists of the robot body, the control device, the remote-control box, and the welding control device. Options include a welder sensor and a positioner. As shown in Figure 3(b), this robot has five action axes: α_1 - α_5. In the teaching mode, each axis may be operated manually and independently by the α system operation, or position teaching may also be carried out in the XYZ rectangular coordinate system (see Figure 3(a)), in which five axes are all linked together. In the playback mode and automatic operation mode, the action is always carried out in the XYZ rectangular coordinate system. As shown in Figure 4(a), after the locations of only two points are taught, the robot is capable of moving the torch at a designated speed along a straight line connecting these two points while holding the torch at a designated angle, with all five axes perfectly synchronized. Moreover, as shown in Figure 4(b), the welding point does not move when the torch angle is changed or the torch is rotated, because the actions of the five axes are perfectly harmonized. Figure 5 illustrates the robot's wide range of action, and Figure 6 shows the robot's range of operation. Both Figure 5 and Figure 6 show the locus of the rotating wrist axis, so these ranges may change somewhat according to the torch attitude. The overall specifications of the robot are as summarized in Table 1.

Table 1. Specifications of RJ 65

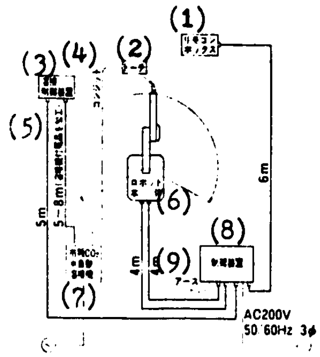
(1) Robot body

Weight: 450 kg
Weight carrying capacity: For arc-welding...torch only
Degrees of freedom: five axes
Drive format: All electric (DC servomotor drive)
Position reproduction accuracy: ± 0.2 mm (axis unit)
Action range and maximum speed:

Axis	Action range	Maximum speed
Rotation (α1)	240° (+120° ~ -120°)	100°/S
Lower arm (α2)	120° (+ 30° ~ - 90°)	90°/S
Upper arm (α3)	270° (+120° ~ -150°)	100°/S
Bending (α4)	180° (+ 90° ~ - 90°)	115°/S
Twisting (α5)	356° (+178° ~ -178°)	180°/S

(2) Control device

Weight: 300 kg
Number of axes controlled: All five axes controlled simultaneously
Path control format: P.T.P. teaching, C.P. regeneration by linear and arc interpolation
Teaching format: Teaching, playback format
Coordinate transformation function: Teaching can be accomplished in either α system or X-Y system; playback is carried out in X-Y system.
Linear interpolation: A straight line passing through two given points in space can be traced at a designated speed.
Arc interpolation: A circular arc passing through three given points in space can be traced at a designated speed.
Speed control format: Controlled steady linear speed (at torch tip)
Position control format: Software servo format
Memory unit: IC memory
External memory unit: Cassette data recorder
Memory step number: 850 steps
Weaving function: (option)
Sensing function: (option)
Speed setting: 2-10 (1 mm/S increment), 12, 14, 16, 20, 50, and 300 MAX mm/S; a total of 16 speeds (maximum speed during teaching: 150 mm/S)
Inching function: 0.2-1 (0.1 mm increment), 1.2, 1.4, 1.6, 2.0, 5.0, 15.0, and 20.0 mm; a total of 16 kinds
External signals: 7 (for input/output)
Timer: 3 kinds (99 divisions between 0.1-9.9 seconds)
Welding condition setting: 5 kinds (stepless adjustment, change possible during welding operation)
Ambient temperature: 0-45°C (0-40°C when cassette recorder is in use)
Power source: AC200V ±10 percent 50/60 Hz 3ϕ 1.5kVA



Key:
(1) Remote control box
(2) Torch
(3) Welding control device
(4) Conduit
(5) Welder accessory work
(6) Robot body
(7) Commercially available semiautomatic CO_2 welder
(8) Control device
(9) Ground

Figure 2. Construction Diagram

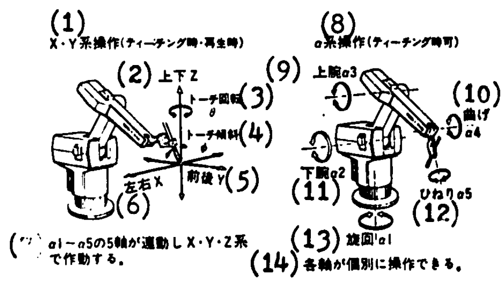


Figure 3. Action Modes

Key:
(1) XY system operation (during teaching and playback modes)
(2) Up/down (Z axis)
(3) Torch rotation axis
(4) Torch tilting
(5) Back/forth (Y axis)
(6) Left/right (X axis)
(7) Action in the XYZ system with coordinated movement of the five axes: α_1 - α_5
(8) System operation (during teaching mode)
(9) Upper arm α_3
(10) Bending α_4
(11) Lower arm α_2
(12) Twisting α_5
(13) Rotation α_1
(14) Each axis may be operated independently

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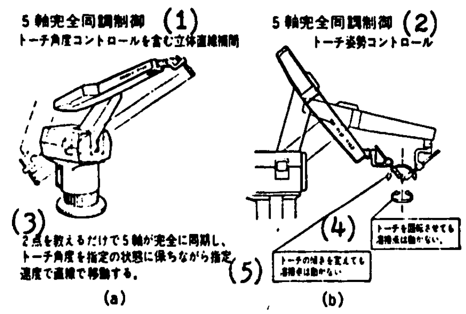


Figure 4. Completely Harmonized Five-Axis Control

Key:
(1) Completely harmonized five-axis control: three-dimensional linear interpolation including torch angle control
(2) Completely harmonized five-axis control: torch attitude control
(3) After the locations of only two points are taught, the robot is capable of moving the torch at a designated speed along a straight line while holding the torch at a designated angle with all five axes perfectly synchronized.
(4) The welding point does not move even when the torch is rotated.
(5) The welding point does not move even when the torch is tilted.

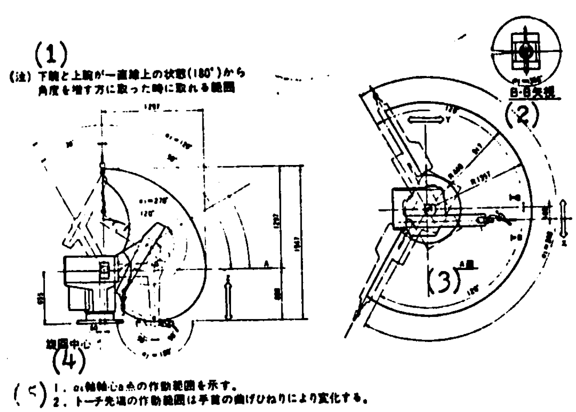


Figure 5. Action Range Diagram

Key:
(1) (Note) The range in the direction of increasing angle from the state in which the lower and upper arms form a line (180°)
(2) The B-B view
(3) A plane
(4) Rotation center
(5) 1. The range of action of a point "a" on the α_1 axis is shown.
2. The range of action of torch tip will vary somewhat according to the bending and twisting of the wrist.

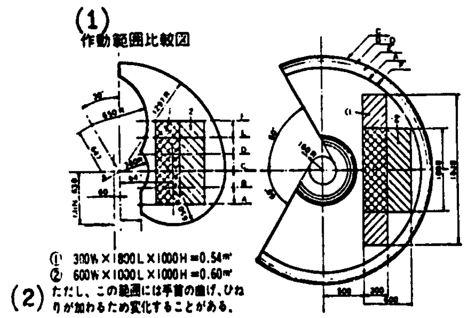


Figure 6. Action Range Comparison Diagram

Key:
(1) Action range comparison diagram
(2) This range will vary somewhat according to the bending and twisting of the wrist.

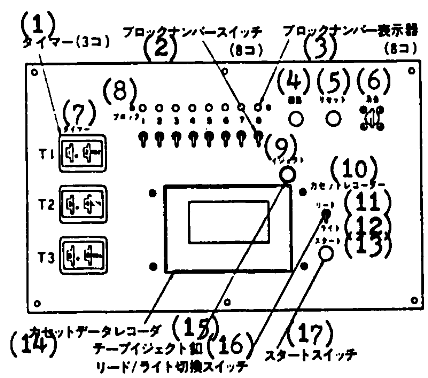


Figure 7. Auxiliary Panel

Key:
(1) Timer(3)
(2) Block number switch (8)
(3) Block number indicator (8)
(4) Edit
(5) Reset
(6) Erase
(7) Timer
(8) Block
(9) Eject
(10) Cassette recorder
(11) Read
(12) Write
(13) Start
(14) Cassette data recorder
(15) Tape eject button
(16) Read/write changeover switch
(17) Start switch

Electronics of RJ 65

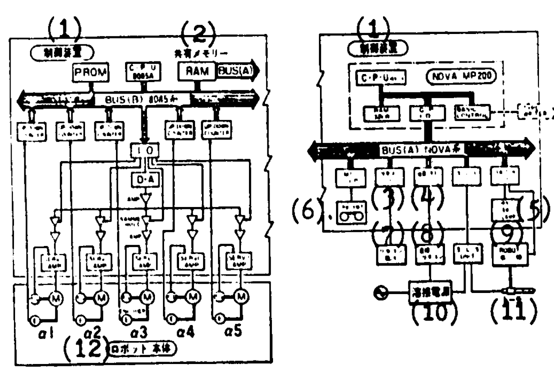
Figure 7 provides a detailed diagram of the control device. The main and the auxiliary panels of the control device are used for control of the power source for the entire system and in particular for control of the operation during the automatic operation period.

As soon as the power source is connected, the cassette data recorder on the auxiliary panel begins to read in the system software data. This lasts approximately 1 minute and 30 seconds. The origin setting switch on the main panel is pressed down next. The five axes of the robot are each equipped with an optic encoder, which feeds back the angle of rotation of each axis. Origin setting means an operation to move the robot to a predetermined position designated as the reference point for action.

Only after the origin is set is the robot able to move freely. The top start switch is used to set the automatic control in motion. The pause switch causes the operation to stop temporarily. The operation resumes when the top start switch is pressed again. An error lamp lights up when an error in operation is detected, and an error code will be displayed on the remote-control box simultaneously. The details of the error can be understood from the error code number. When the emergency stop switch is pressed, the operation stops instantly no matter what state the robot may be in.

Eight different types of operation can be performed by selecting any one of them using the block number switch on the auxiliary panel. The editing switch enables editing of a sequence of operations according to the block number. When the editing switch is pressed twice, the operation becomes endless, and a sequence of operations will be repeated again and again.

The timer is used to set the pause time between steps.



Key:
(1) Control device
(2) Common memory
(3) Remote control I/O
(4) Welding remote-control I/O
(5) Panel SW LAMP
(6) Cassette MT
(7) Remote control box
(8) Welding remote-control
(9) Robot body
(10) Welding electric power source
(11) Torch
(12) Robot body

Figure 8. Control System Diagram

Figure 8 illustrates the control system diagram. A 16-bit computer and a DRAM 32 kW memory are used. This computer is a high-performance microcomputer with a microprogram control format using a high-speed bipolar microprocessor. Its characteristics include: add command 0.84 microseconds, multiply command 4.9 microseconds, and high-speed data channel 1.85 MHz. Various I/O interface connections are connected to the BUS, which is connected to the CPU via a GP I/O interface. The robot body and all its components are connected to the computer via these I/O interfaces. The main and the auxiliary panels, the remote-control box, as well as the switches and lamps described above are also connected to the BUS through their own I/O interfaces.

In addition, there are also limit switches for various robot axes which are activated when the action reaches a preset limit, the welding control box, and the I/O interface for sensor unit; the drive system employs the software servo format. There are five independent drive systems for the five axes; each system consisting of a servo amplifier and a servomotor. Each servomotor has its own tachogenerator and encoder which generate the feedback signals used for the speed and position control. The CPU used for the softservo application is connected with the main CPU through the common memory and receives timely position command value from it. The action angle of each axis is determined as follows: the pulses generated by the encoder are counted by the UP/DOWN counter and the output value is determined by comparing this value with the command value. Moreover, a single D/A converter is shared by the five axes by switching from one to another sequentially. This does not pose any problem, because the time interval is sufficiently short compared with the servo system action.

Software

Coordinate transformation: Teaching is accomplished either in the α system or in the XY system, and playback action is carried out in the X-Y system. Inside the CPU, coordinate transformation from the α system to the X-Y system is calculated first, and the results thus obtained are stored in the memory as the teaching point data together with all data in the remote-control box.

During the playback action period, the data are retrieved from the memory and computation is carried out in the X-Y system. Take the case of linear interpolation, for example. The distance between the two teaching points will be divided by the velocity to find the time, then the new position to which the robot must move during each time interval will be calculated. The distance of travel from the present position to the new position will then be converted to the α system through coordinate transformation, and outputs to α_1 - α_5 axes will be generated. The robot will trace a straight line connecting the two points at a designated speed with a position reproduction accuracy of ±0.2 mm.

Arc interpolation: As shown in Figure 9, if three points in space are given, the robot will trace a circular arc passing through these three points at a designated speed. A complete circle can be traced if four points are given, as shown in Figure 9. If an additional point is given in addition to a set of

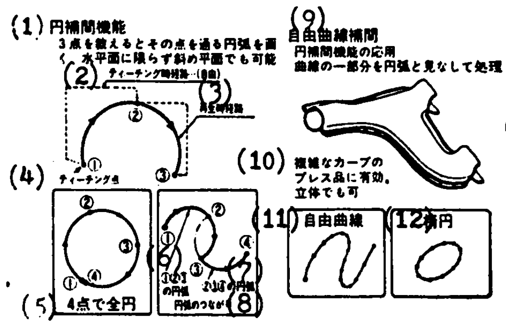


Figure 9. Arc Interpolation Function Diagram

Key:
(1) Arc interpolation function: An arc passing through three given points can be traced; the three points may be on a horizontal plane or on a slanted plane.
(2) Path during teaching mode (arbitrary)
(3) Path during playback mode
(4) Teaching point
(5) A full circle from four points
(6) Arc of points 1, 2, and 3
(7) Arc of points 2, 3, and 4
(8) Connected arcs
(9) Arbitrary curve interpolation: Application of arc interpolation; small section of a curve treated as an arc
(10) Useful in tracing complicated curve of press work; applicable to 3-D also
(11) An arbitrary curve
(12) An ellipse

three points which define an arc, the first point will be omitted and the robot will trace an arc passing through the remaining two points and the additional point. An arbitrary curve can be traced by a series of operations of this type.

Weaving function: This function is achieved by a software format as shown in Figure 10. The pattern is arbitrary. Once the robot is taught a single pattern is entered into the system as a menu, that pattern can be called and used elsewhere.

Torch offset correction function (Figure 11): The standard torch has offset, so it can be used with ease even in a narrow space.

Sensing system [Figures 12-14): This is a unique sensorless sensor. No special sensor other than the torch itself is used. The welding wire itself is used as the sensor. Its principle of operation is as shown in the drawing.

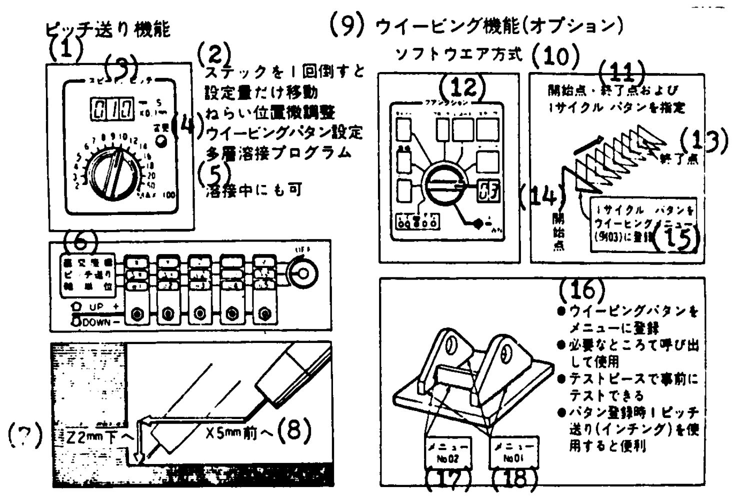
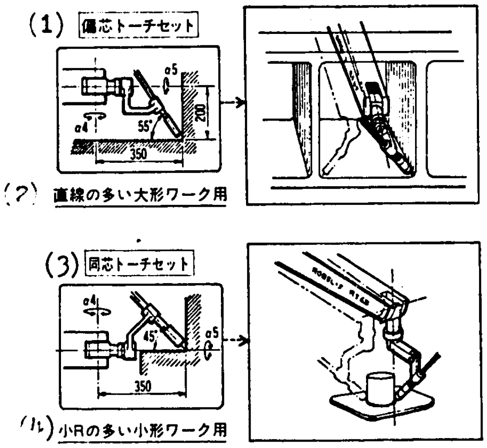


Figure 10. Pitch Feed and Weaving Functions

Key:
(1) Pitch feed function
(2) A designated amount is traveled each time the stick is down; fine adjustment of the target position; setting weaving pattern; multilayer welding program
(3) Speed/pitch
(4) Change
(5) Change can also be implemented during welding operation
(6) Rectangular coordinates/pitch feed/axis unit
(7) 2 mm down in Z-direction
(8) 5 mm forward in X-direction
(9) Weaving function (option)
(10) Software format
(11) Setting the starting point, terminal point and the single cycle pattern
(12) Function (clockwise): EXT/Weld/Timer/Block/Record/Step/Sensing/Weaving
(13) Terminal point
(14) Starting point
(15) A single cycle pattern is registered in the weaving menu (No 03, for example)
(16) Weaving pattern is registered in menu; the menu is called and used whenever necessary; menu can be tested with a test piece prior to the operation; the menu will be easier to use if 1 pitch feed (inching) was used when the pattern was registered
(17) Menu No 02
(18) Menu No 01



Key:
(1) Offcenter torch set
(2) For large work with many straight lines
(3) Concentric torch set
(4) For small work with many small R's

Figure 11. Torch Offset Correction Function of RJ 65 (for five-axis simultaneous control). If necessary, the torch tip may be attached in such a way that it is off the α_5 axis.

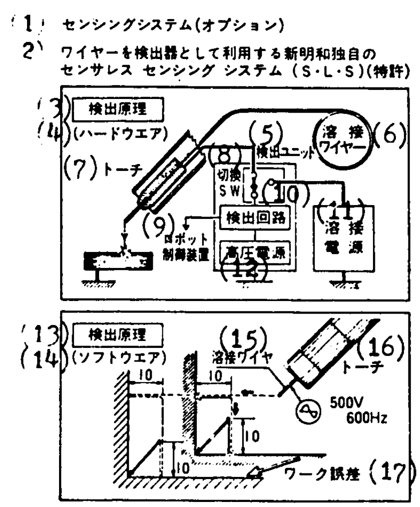
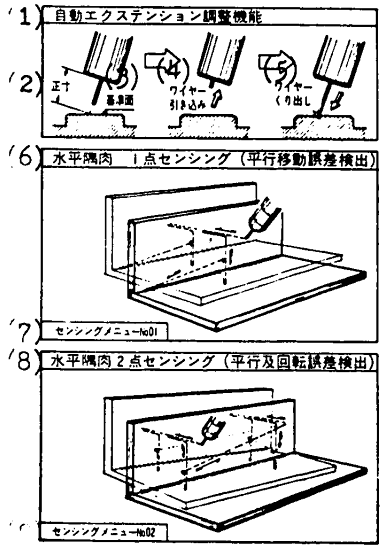


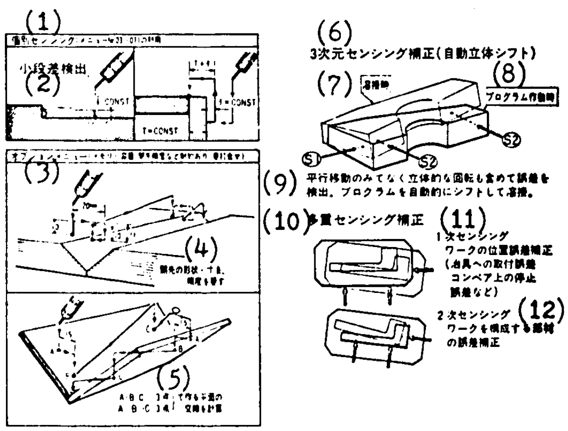
Figure 12. Sensing System

Key:
(1) Sensing system (option)
(2) Shinmeiwa's unique sensorless sensing system (S.L.S.) (Patent) using welding wire as detector
(3) Principle of detection
(4) Hardware
(5) Detection unit
(6) Welding wire
(7) Torch
(8) Changeover switch
(9) Robot control device
(10) Detection circuit
(11) Welding power source
(12) High-voltage power source
(13) Principle of detection
(14) (Software)
(15) Welding wire
(16) Torch
(17) Work error



Key:
(1) Automatic extension adjustment function
(2) Correct dimension
(3) Reference surface
(4) Wire retracted
(5) Wire extended
(6) Horizontal fillet: one-point sensing (detection of parallel travel error)
(7) Sensing menu No 01
(8) Horizontal fillet: two-point sensing (detection of parallel travel error and rotational error
(9) Sensing menu No 02

Figure 13. Sensing System (automatic extension function)



Key:
(1) Application of individual sensing (menu Nos 03-07)
(2) Detection of small step error
(3) Option menu (memory capacity and groove accuracy are restricted; needs advance arrangement)
(4) Shape, dimension and accuracy of groove needed
(5) Line formed at the intersection of two planes formed by points A, B, and C and points A', B', and C' is calculated.
(6) Three-dimensional sensing correction (automatic three-dimensional shift)
(7) During welding operation
(8) During program action
(9) Detection of error due not only to parallel travel but also to three-dimensional rotation; welding operation is carried out by automatically shifting the program.
(10) Multiple sensing correction
(11) Primary sensing: correction of work position error (such as installation error on the jig and positioning error on conveyer)
(12) Secondary sensing: correction of errors on components of the work

Figure 14. Sensing system (types of sensor)

High-voltage electricity, 500 V, 600 Hz, is applied to the torch to detect its grounding condition. The present position and the instructed data are compared, and the position error is corrected.

Since the extended length of welding wire is a reference, it is adjusted by the automatic extension mechanism first of all as shown in Figure 13. The sensor is determined by the menu number. For example, sensing menu No 01, as shown in Figure 13, is a combination between a vertical sensor and a sensor for torch orientation detection. Sensing menu No 02 is a two-point sensor menu. Figure 14 illustrates a number of applications, including downward fillet welding, three-dimensional sensing and multiple sensor.

Conclusion

The Robel J was developed as an arc-welding robot. This product is based on an advanced mechatronics technology developed over a period of more than 10 years and reflects the know-how of this company concerning welding accumulated with inputs from the users over the years.

The Robel J is characterized by its wide action range and its advanced software package. Action with flexibility can be easily realized through addition of new menus or subroutines. We, the maker, are planning to diversify its application beyond the welding operation, and users' opinions in this regard are welcome.

Hitachi Limited's 'Mr Aros'

Tokyo DENSHI GIJUTSU in Japanese Vol 24 No 1, Jan 82 pp 74-77

[Article by Hitoshi Yoshida, Robot Department, Shushino plant, Hitachi Ltd; Kazuma Ito and Yasuo Saito, Design Department, Hitachi Kyoba Engineering: "Mr Aros and the Electronics"]

[Text] The work objects of arc-welding robots consist mainly of a large variety of large, thick products for medium and small production. Therefore, assurance of accurate path control, adaptability for dimensional errors of the work objects, and improved operability are demanded. We have solved these problems by a combination of miniature noncontact type sensor and microprocessor capability and have gone further to insure the reliability and safety of our machine, which is well received by the user.

In this article we will outline the hardware and the software which brought about the various functions referred to above.

Specifications of the Welding Robot System

The robot specifications are determined by the work object and the work detail the robot is expected to handle. The work attitude control that is required during the welding operation is handled by the positioner.

Automatic welding of almost all types of welding lines can be accomplished through a combination of a robot having standard specifications and a positioner which matches the shape of the work object. Figure 1 illustrates the external appearance of a standard robot and a positioner and Table 1 summarizes their specifications.

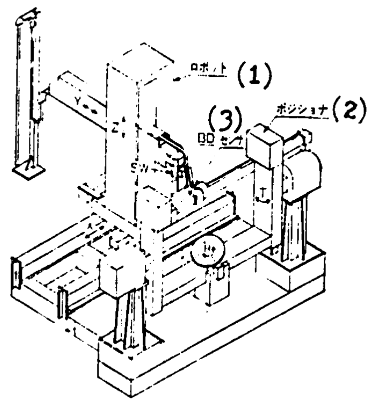


Figure 1. External Appearance of Robot and Positioner

Key: (1) Robot (2) Positioner (3) Sensor

Table 1. Specifications of Robot and Positioner

Robot body		
	Item	Specification
Action range	X (Walk)	1500 mm
	Y (To and fro)	1000 mm
	Z (Up and down)	1100 mm
	SW (Swing)	± 100°
	BD (Bend)	-5° ∼ 50° (from down)
	Sensor retraction	50 mm
Position reproducibility		± 1.0 mm
Hydraulic pressure source		70 kg/cm^2 normal pressure
Pneumatic source		4 kg/cm^2 or more
Power source		200V 3Ø 5.5 kVA
Weight		1500 kg approx.
Speed	Welding (torch tip)	150-990 mm/min
	Fast feed	6000 mm/min

Positioner body		
	Item	Specification
Action range	R (rotation)	± 200°
	T (Twisting)	± 200°
Speed	Welding	18°-114°/min
	Fast feed	660°/min
Work weight		600 kg including jig)
Power source		AC 200V 3Ø 1.5 kVA
Maximum allowable off-center loading		20 kg-m

Control Device

The basic control format of this arc-welding robot system consists of PTP teach format and CP control format combined with a magnetic sensor. The system has the following control functions:

1) Sensor function: The sense information enables the robot to accurately aim its torch on the welding line.

2) Check function: The robot is capable of checking with its sensor the deviation between the welding line on the work object and the teaching data and automatically corrects the position data prior to the playback operation.

3) Corner point coordinate computation function: It is usually difficult to accurately teach the corner section of a work object. The robot is capable of automatically calculating the corner formed by the intersection of two straight lines from the available information taught and then controlling various axes of the robot.

4) Linear interpolation function: The robot is capable of tracing a straight line passing through two teach points at a designated fixed linear speed by carrying out linear interpolation computation.

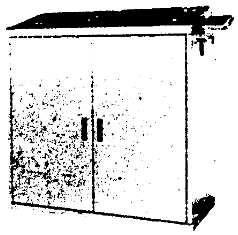
5) Wrist correction function: The action of the robot's main axis can be controlled so that the aim of torch tip will remain fixed even while the two wrist axes are moved.

6) Follow control function: Welding operation is carried out by following the welding line with a sensor.

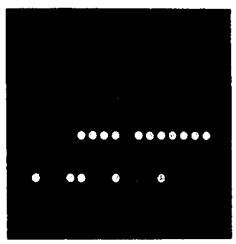
7) Angle correction function during checking, weaving function, unilateral sensor function, and arc interpolation function can be added as options.

The construction of the control device is centered around a microcontroller using a microprocessor, and the majority of the functions listed above are implemented by means of software, so the number of parts can be reduced and the reliability of the device increased. Figure 2 shows the construction of the control device; Photograph 1, its external appearance; Table 2, its specifications; and Photographs 2 and 3, the external appearance of the operation console and the teaching box, respectively.

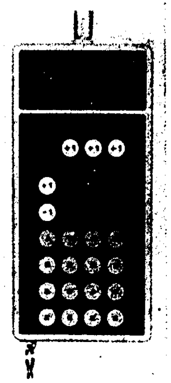
As shown in Figure 2, each unit is subdivided according to the function and is connected with the system bus. The master CPU in charge of the control of the entire system, the SVU unit in charge of the control of the position servo system, the operation console, the teaching box, the peripheral equipment, and the IOP unit in charge of connection, all employ a multiprocessor format equipped with a microprocessor in order to shorten the time of computation and processing. The memory device consists of a core memory used on-line and a cassette tape deck (CMT) for storing operation program off-line. Various necessary functions are also included in the handy teaching box; special consideration is given in the arrangement of the buttons, and the number of signal cables is reduced through adoption of series transmission format for the convenience of the operator.



Photograph 1. External appearance of the control device



Photograph 2. External appearance of the operation console



Photograph 3. External appearance of the teaching box

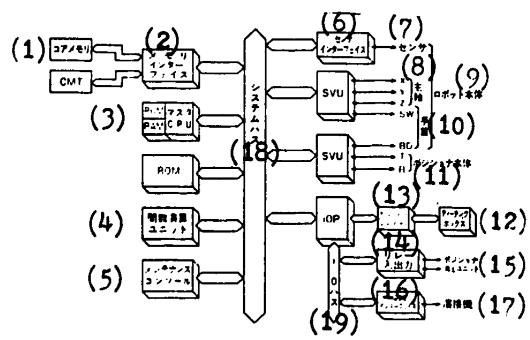


Figure 2. Construction of Control Device

Key:
(1) Memory core
(2) Memory interface
(3) Master CPU
(4) Function computation unit
(5) Maintenance console
(7) Sensor
(8) Main axes
(9) Robot body
(10) Wrist
(11) Positioner body
(12) Teaching box
(13) Operation console
(14) Relay input/output
(15) Positioner hydraulic unit
(16) Welder interface
(17) Welder
(18) System bus
(19) I/O bus

Table 2. Specifications of Control Device

Item		Specifications
Teaching format		Remote teaching by teaching box
Control format		CP control through linear interpolation and PTP teaching
Control axis number		Electric hydraulic servo: 5 axes maximum (for robot) Electric servo: 2 axes maximum (for positioner)
Position detection		Potentiometer
Position control		Software servo format
Position memory		Core memory
Memory number 436 steps		
Program division number		Maximum of 4
Speed control		Constant linear speed
Speed Control	Welding	150-990 mm/min (7 steps) may be changed during welding
	Fast feed	6000 mm/min
Welding current		256 division maximum (6 steps) May be changed during welding
Welding voltage		256 division maximum (6 steps) May be changed during welding
Addition, correction, and elimination of teaching point: Possible		
Computation function		Sense function Check function Corner point coordinate computation function Linear interpolation Wrist correct function Follow control function
Abnormality detection function		Torch contact Arc break Detector CPU abnormality Sensor abnormal approach Wirefeed failure No air supply Hydraulic pressure source abnormality
Trouble diagnosis		Yes
Auxiliary memory unit		Cassette deck
Power Source	For control	AC100V (±10 percent) 50/60 Hz single phase 1.5 kVA
	For hydraulic	AC200V (±10 percent) 50/60 Hz three phase 5.5 kVA
	For positioner	AC200/220V (±10 percent) 50/60 Hz three phase 1.5 kVA
External Dimension	Robot	1100 W x 544D x 1134H
	positioner	500 W x 544D x 1500H
Protective construction		Dust-proof type
Ambient temperature		0-40°C
Weight	Robot	250 kg
	Positioner	350 kg
Color of coating		Exterior — Munsell 7.5 BG 6/1.5 Interior — " Method of application — Spray painting
Option functions		1. Weaving function of wrist up/down bending axis 2. Shift function 3. Unilateral sensor function 4. Axis modification function 5. Check angle modification function 6. Arc interpolation function 7. Increase in memory number 476 steps (SP, JP, JLP type) Increase in memory number 512 steps (SL type)

Figure 3 shows the block diagram of the SVU system. The microprocessor installed on the SVU unit is connected with the system bus as a slave, and the interface delivers and receives data (commands, various types of parameters) command and status using a pseudodual port RAM (a RAM capable of reading/writing independently from the system bus and the microprocessor in the SVU unit) using software. The operation output (servodrive output) consists of 2 kHz short form wave obtained after an 8-bit data[1] is subjected to D/A conversion by the PWM (pulse width modulation) circuit. The position feedback consists of a signal obtained after the potentiometer output is subjected to A/D conversion (12-bit).[2]

During the teaching process of a robot having playback control format, the operator must step into the action range of robot. This means that a human accident could be caused by a runaway robot or positioner. Therefore, careful attention must be paid to the matter of safety.

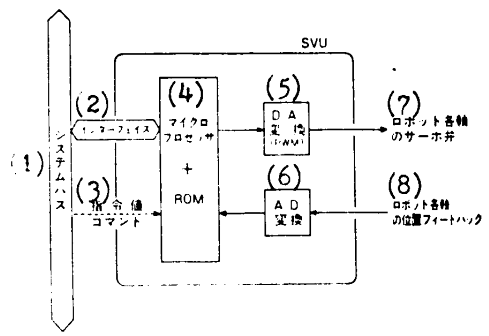


Figure 3. Block Diagram of SVU Unit

Key:
(1) System bus
(2) Interface
(3) Command
(4) Microprocessor
(5) D/A conversion
(6) A/D conversion
(7) Servo valve of each axis of robot
(8) Position of feedback of each axis of robot

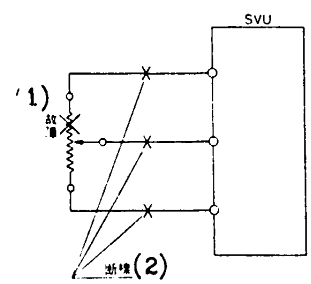


Figure 4. Detection of Abnormality Such as Potentiometer Breakage

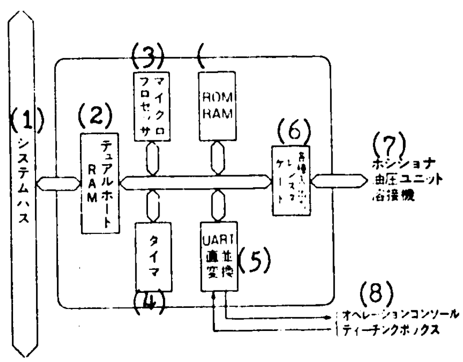
Key:
(1) Trouble
(2) Broken wire

The unit is equipped with an abnormality detection circuit (see Figure 4) which can prevent the robot or the positioner from running away even if a breakdown in the potentiometer or a breakage in the circuit should take place.

1, 2 The data length is not fixed. It is variable according to the effective stroke of the robot and the accuracy requirement.

2. Input/Output Interface

Figure 5 shows the block diagram of the IOP unit. Almost all input/output information required for the operation of the system are grouped together and the information is transferred to the master CPU via the 256-byte dual port RAM. The UART transfers data concerning the button, digital display, and light-emitting diode via the series-parallel conversion board contained inside the operation console and the teaching box. Moreover, various input/output registers are constructed of an 8-bit parallel bus belonging to an independent I/O, and the input/output information of the peripheral equipment are transferred via the relay input/output unit or the welder interface unit.



Key:
(1) System bus
(2) Dual port RAM
(3) Microprocessor
(4) Timer
(5) UART series/parallel conversion
(6) Various input/output register gates
(7) Positioner hydraulic unit/ welder
(8) Operation console/teaching box

Figure 5. Block Diagram of IOP

3. Sensor Interface

If the robot orbit is to be modified according to the work object, a sensor which can detect the distance between the work and the torch becomes necessary. A contact-type sensor used in the automatic follow device has a number of disadvantages, including the fact that it is affected by sputter, scale, temporary welding, and defects.

The sensor used in "Mr Aros" is a noncontact type magnetic sensor which will not be affected by the arc heat, sputter, surface condition of the work, fumes, or external noise unique to arc-welding.

Its principle of operation utilizes the change in magnetic flux, and as shown in Figure 6, it consists of excitation coil C_0, and detection coils C_1 and C_2. By connecting the two detection coils C_1 and C_2 of the same winding in the differential action format, the change in magnetic flux due to the eddy current generated between the work and the coil can be detected. The thermal performance of this sensor is characterized by an error of the order of 4 percent when used at a temperature of 200°C or less and a distance in the range of 0-8 mm from the work. Figure 7 shows a block diagram of the sensor interface. When excitation coil C_0 is excited with a 20 kHz AC wave form, output voltage will be induced in detection coils C_1 and C_2. If this output voltage is amplified and waveform shaped, a curve like those shown in Figure 8

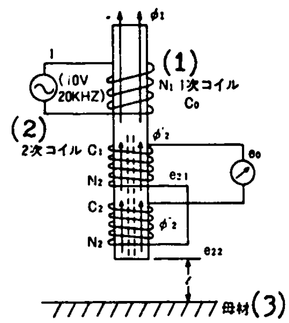


Figure 6. Principle Diagram of Noncontact Type Sensor

Key:
(1) Primary coil
(2) Secondary coil
(3) Material

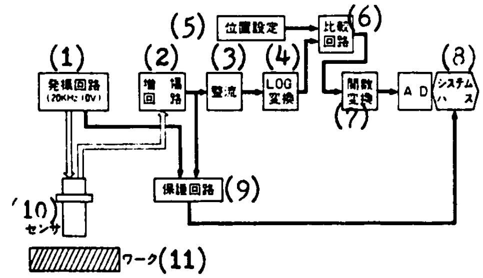


Figure 7. Block Diagram of Sensor Interface

Key:
(1) Oscillation circuit
(2) Amplifier circuit
(3) Rectification
(4) LOG conversion
(5) Position setting
(6) Comparison circuit
(7) Function conversion
(8) System bus
(9) Protection circuit
(10) Sensor
(11) Work

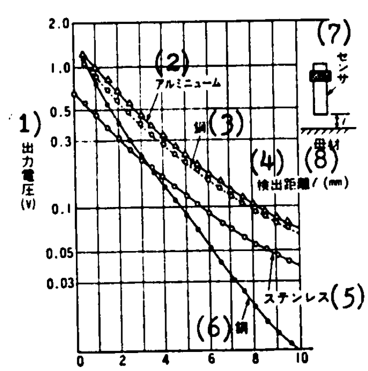


Figure 8. Sensor Output Characteristics

Key:
(1) Output voltage
(2) Aluminum
(3) Copper
(4) Detection distance
(5) Stainless steel
(6) Steel
(7) Sensor
(8) Material

can be obtained. To use this signal in the various functions described above, the signal is subjected to an A/D conversion at the last stage. Like the abnormality detection circuit described previously, this circuit also contains a protection circuit which can prevent robot runaway if a primary or secondary breakage of sensor cable should take place or if the sensor should come too close to the work object, exceeding a designated distance.

Software

The majority of the functions of this robot are realized through software. The basic construction of the software is illustrated in Figure 9. The process monitor system (PMS) carries out multiple processing of various tasks. It executes a task according to the priority order when an interruption occurs (such as an input/output press-button). A high-level starting priority is assigned to tasks related to emergency and abnormality treatment, and all individual tasks are carefully ordered by taking into consideration the detail of treatment so as to shorten the treatment time. At the end of a task, the control is returned to the PMS. During the execution of a task, if the starting conditions for a task having higher priority order should be established, the PMS would withdraw all registers of the present task and execute the task that had been inserted. Table 3 summarizes the tasks that are actually used and Table 4 shows a summary of the subroutines.

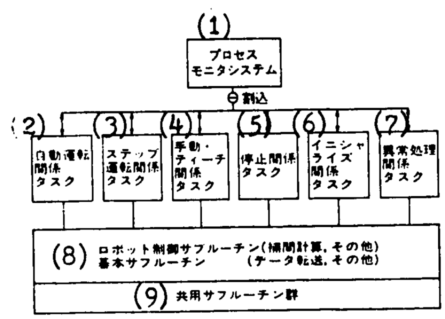


Figure 9. Basic Construction of Software

Key:
(1) Process monitoring system
(2) Tasks related to automatic operation
(3) Tasks related to step operation
(4) Tasks related to manual operation and teaching
(5) Tasks related to stopping
(6) Tasks related to initialization
(7) Tasks related to emergency treatment
(8) Robot control subroutine (interpolation and other); basic subroutine (data transfer and other)
(9) Common subroutine group

Table 3. A List of Tasks (classification and assignment of tasks)

Important factor	Abbreviated symbol	I/O	Remarks
02	ESTOP	I	Emergency stop
03	STOP	I	Instant stop
04	ABNMI	I	Abnormality I (same as intant stop)
05	BSTOP	I	Block stop
07	CSTOP	I	Cycle stop
10	RCVRY	I	Recovery from emergency stop
11	LOAD	I	Hydraulic pressure loading
12	ULOD	I	Hydraulic pressure unloading
13	CTAUT	I	Switch automatic mode
14	CTSTP	I	Switch step mode
15	CTMAN	I	Switch teach mode
20	STUPO	I	Step and group center operation
42	EMGG	O	Emergency stop on
53	MANDV	O	Manual operation
55	TEACH	O	TEACH TASK
60	STOPG	O	Instant stop on
63	STEP	O	Step operation
67	AUTCR	O	Automatic operation
72	AMODG	O	Automatic mode on
77	CPUIT	O	CPU INITIALIZE

——Important factor for starting

I : interrupt
O : OUEUE

Table 4. A List of Subroutines (standardized subroutines for Aros series)

No.	Name	Abbreviated symbol
1	Transfer	MOVE
2	RAM CLEAR	CLEAR
3	ENCODE DATA	ENCOD
4	DECODE DATA	DECOD
5	Multiplication	MULT
6	Division, one of them	DIVI
7	$\sqrt{N}$	SORT
8	CORE MEMORY Read core memory	RCORE
9	CORE MEMORY Write core memory	WCORE
10	Quadruple length addition	AD 4
11	SINE	SIN
12	Corner computation	CCRNR
13	COSINE	COS
14	Index matching	MEXP
15	Normalization	NORM
16	Multiply floating	MF
17	Absolute	ABS
18	BCD to binary	BCDTB

A delicate abnormality treatment function and interlocking function which could not be achieved in the conventional robot, were realized through the use of software. The rationality checks--more than 30 in number-- which maintain surveillance over the operator teach error and the operation error, have a significant effect on prevention of accident and increasing the teaching work number, by teaching the operator in advance, unlike the conventional robot, with which the teaching errors can be revealed only after it is played back. Table 5 summarizes the causes of abnormalities which are checked and the details of their treatment.

Table 5. Cause of Abnormality and Its Treatment (abnormalities being checked and details of the treatment)

Signal name	Cause of abnormality	Details of treatment
Emergency stop	Emergency stop button pressed	Deviation signal to servo valve OFF Stop arc Emergency stop lamp ON Stop positioner Hydraulic power source OFF (unload simultaneously)
Abnormal oil temperature A	Oil temperature > 50°C	Block stop
Abnormal oil temperature B	Oil temperature > 60°C	Same as emergency stop Abnormality display (main console)
Motor overload	Thermal trip on hydraulic unit	Same as emergency stop Abnormality display (main console)
Encoder lamp broken	Lamp inside encoder broken	Same as emergency stop Abnormality display (main console)
Torch contact	Torch touches work	Same as emergency stop Abnormality display (main console)
CPU abnormality	CPU fails to operate	Same as emergency stop Abnormality display (main console)
Teaching box abnormality	Abnormality in teaching box circuit or missed transmission from teaching box	Same as emergency stop Abnormality display (main console)
Broken arc	Overall abnormality of welding power source	Instantaneous stop of automatic operation Abnormality display (main console)
Sensor abnormality	Broken sensor or abnormal approach to work	Same as emergency stop Abnormality display (main console)

The industrial robots are about to change from lonesome stable robots to ranch robots with social status thanks to the development of the microprocessor. It is the task of the maker to realize the dream robot of the user.

9113
CSO: 4106/46

SCIENCE AND TECHNOLOGY

CREATIVE SCIENCE, TECHNOLOGY PROMOTION PROGRAM BEING SET UP

Outline of Program

Tokyo NIHON KOGYO SHIMBUN in Japanese 6 Jan 82 p 2

[Text] A Greater Degree of Freedom: The Path to Success for the Creative Science and Technology Promotion Program

The Science and Technology Agency announced the "Creative Science and Technology Promotion Program" as one of its new policies for the 1980's. It began in 1981 with an initial budget of approximately 600 million yen. At the end of October last year, the general directors of four research projects were named, and now a total of 80 researchers (about 10 percent from overseas) are being selected. By the end of March all personnel will be selected and the research is scheduled to get under way in earnest.

This program abolishes the concepts of previous science and technology policies and aims at promoting science and technology with an "individual-centered organization." An increase to 1.98 billion yen was approved in the 1982 budget. However, in order to achieve the final goals, the people involved from industry, government, and academia must all recognize that this is a "difficult project" which requires a great turnaround in thinking.

The Creative Science and Technology Promotion Program, along with the "Next-Generation Basic Industrial Technology R and D Program," is a major part of the government's proposed policy for building the country on the basis of science and technology in the 1980's. The thinking behind it is quite unusual.

The creative science program is a plan for selecting people of exceptional ability to be general directors, gathering superior researchers under their leadership by contract from industry, government, and academia, and using existing research facilities to carry out highly original research. The purpose of the program is to discover the "seeds" of science and technology which can become the source of innovative technology. The aim throughout is to carry out research in an "individual-centered" way which will make the most of the ability of creative and ambitious researchers.

In accordance with the conclusions of the Council for Science and Technology, the New Technology Development Corporation, which is the parent body for promoting the new program, selected the four following subjects on which to begin research in 1981: super-fine particles, specially structured substances, fine polymers, and perfect crystals. A researcher-president of a private company and three university professors have been chosen as general directors. Some of the research has already begun, but it will start in earnest in April. In addition, "holonic function" and "bioinformation" have been selected as new research subjects for 1982.

In view of these conditions, it would seem likely that the Creative Science and Technology Promotion Program would go ahead smoothly, but in reality, this is not necessarily true.

The reason is that it is an "individual-centered" research and development project, which differs in concept from the previous government-led projects. Even if it is suited to creative activity, it is doubtful whether it can be easily accepted by Japan's industrial society.

For example, there is the problem of retaining researchers. At present, there is great interest in the various industrial sectors and it is necessary to refuse some applications for participation. However, in the long term, there is a problem of whether Japanese industry, with its principle of "company loyalty comes first because of lifetime employment," can accept a research organization that gives priority to the individual.

In any case, we hope that the related institutions will respond with greater freedom in order to at least reward the efforts of the general directors, among whom are included representatives of industry who believe that this is a public service and that the profit of private corporations comes second.

Research Setup

Tokyo NIKKEI SANGYO SHIMBUN in Japanese 12 Feb 82 p 15

[Text] Sixty-Eight Researchers Including Foreigners; New Technology Corporation's Creative Science Program; 15 Locations Selected for Research Facilities

The New Technology Development Corporation is hurrying to organize the "Creative Science and Technology Promotion Program" which began last fall. The places where the research is to be carried out and the persons who will perform the research, including the group leaders, have been mostly determined. The equipment and instruments necessary for each research theme are being ordered, and the main research activity will begin early in FY-82. Research will be carried out at 15 locations, and there will be 68 researchers including the group leaders (30 of these are scheduled to sign contracts by March). Eight of the researchers are foreigners.

The Creative Science and Technology Promotion Program will work on four projects expected to be the seeds of next-generation technology innovation: 1) super-fine particles, 2) specially structured substances, 3) fine polymers, and 4) perfect crystals. These projects will be undertaken in a 5-year plan under a new system known as a flexible research system. Superior researchers will be gathered for the projects from industry, academia, and government and placed under project leaders who are excellent researchers with managerial ability. This program will work under a person-centered research system. The research locations and the number of researchers for each project are as follows.

Super-fine particles (project leader: Shuzei Hayashi, president of Nippon Vacuum Technology)--1) basic material properties: Meijo University Science and Engineering Department (Nagoya), five researchers; 2) physical application: Gakei Electric (Tsukuba Research and Education Garden City), four researchers; 3) biochemical application: Maruzen Oil Company (Satte-machi, Saitama Prefecture), four researchers; 4) method of refining: Nippon Vacuum Technology Ultimate Materials Laboratory (Sanbu-gun, Chiba Prefecture), four researchers.

Specially structured substances (project leader: Takeshi Masumoto, Tohoku University professor)--1) basic physical properties: Electromagnetic Materials Laboratory (Sendai), six researchers; 2) amorphous compounds: Otsuka Chemical and Pharmaceutical Company (Tokushima), four researchers; 3) amorphous metal thin films: Gakushuin University (Tokyo), three researchers; 4) special ceramic materials: Furukawa Electric Central Research Laboratory (Tokyo), four researchers; 5) intrastratal compounds: (will be researched in basic material properties group during 1981), one researcher.

Fine polymers (group leader: Naoya Ogata, Jochi University professor)--1) molecule design: Jochi University Science and Engineering Department (Tokyo), four researchers; 2) selective function materials: Mitsubishi Chemical Industries General Laboratory (Yokohama), five researchers; 3) organic electron materials: Matsushita Technical Laboratory (Kawasaki), five researchers.

Perfect crystals (group leader: Junichi Nishizawa, Tohoku University professor)--1) basic structure: Semiconductor Laboratory (Sendai), seven researchers; 2) super-high-speed elements: Mitsubishi Electric (Itami, Hyogo Prefecture), four researchers; 3) perfect crystal manufacturing process: Mitsubishi Metals (Omiya, Saitama Prefecture), four researchers; 4) optical application: Hamamatsu Television (Hamamatsu), four researchers.

9651
CSO: 4106/65 END