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SUMMARY REPORT ~~#9~~ #8

ON

WORK ORDER NO. 9,
TASK ORDER NO. 9

September 20, 1962

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(2) Overheating is not a problem for no-load operation without or with water, or for full-load operation when water is passed through the unit (to the diamond drill).

(3) Stalling and overloading cause motor failure.

(4) The 230-volt unit is significantly more susceptible than the 115-volt unit to failure as a result of manufacturing inaccuracies and operational abuse.

As a result of this work, it is recommended that the drilling units presently available to you be used to obtain field reaction to the operational performance of the drilling equipment. Detailed procedures for this are given in the report. It is also recommended that a preliminary design study be undertaken to determine whether the drilling unit can be significantly improved in light of the performance information to be obtained from the field.

We have enjoyed working on these projects. The history of the development of the drilling equipment is complicated, and the future possible developments of the equipment encompass many alternatives. We look forward to the opportunity to discuss possible future developments with you and your associates.

Sincerely,

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Enclosure

In Triplicate

SUMMARY REPORT

ON

WORK ORDER NO. 9,
TASK ORDER NO. 9

September 20, 1962

INTRODUCTION

This report summarizes the work done under two programs relative to the improvement of 230-volt DC drilling units incorporated in specialized drilling kits. Work Order No. 6, Task Order No. 9, was undertaken on March 16, 1962, to study certain problems which had arisen in the manufacture and use of the 230-volt units. Work Order No. 9, Task Order No. 9, was undertaken on May 15, 1962, to investigate the problems in greater detail and to evolve recommendations for the correction of the problems. To make the discussion of the results of both programs more meaningful, they are presented together in this report.

In the course of the development of the above-mentioned specialized drilling kits, it had been decided that some of the drilling units should be equipped with motors for operation on 115-volt current, and some with motors for operation on 230-volt current; corresponding experimental units had been designed and fabricated, and also appropriate specifications and drawings had been prepared. The Sponsor subsequently had incorporated modifications in the design and then procured a number of drilling kits via two commercial fabricators. On the basis of recent manufacturing and field experience with the corresponding drilling units, the Sponsor had indicated that the drilling units equipped with 115-volt motors had operated satisfactorily; however, considerable difficulty had been encountered with the 230-volt units. In some cases, the motors had appeared to be unsatisfactory as supplied by the manufacturer. In other instances, they had developed "shorts" after brief periods of operation in the field. Because of the frequency of occurrence of trouble with the 230-volt motors of these drilling units, Work Order No. 6, Task Order No. 9, was undertaken to investigate the cause(s) of the difficulty, and, if possible, to ascertain what measures might be taken to rectify the difficulty.

It had been envisioned that the Work Order No. 6 program would start with a review of the use pattern of the 230-volt drilling unit from the viewpoint of the motor and with the examination of a unit found to be unsatisfactory for use. This unit was to be compared with one considered to be satisfactory. A visit was to be made to the motor manufacturer to review the manufacturing process and discuss the problem with their engineering staff. It had been expected that these efforts would determine a reasonable cause for the difficulty. Ideas for improvement were then to be considered and one or two were to be selected. To the extent possible, a drilling unit was to be modified accordingly, evaluated in our laboratory under simulated service conditions, and delivered to the Sponsor for further evaluation.

The effort performed under Work Order No. 6 progressed somewhat differently as a result of discussions and mutual agreement with the Sponsor. The examination of available data on failed units showed a much wider spread of performance than had been originally anticipated. Therefore, it was considered necessary for us to examine as many 230-volt drilling units as possible, to obtain a better picture of the various causes of failure. Consequently, 43 "off the shelf" drilling kits equipped with 230-volt drilling units were furnished to us. The drilling units were disassembled and selected parts were examined; these parts were the ones thought to be most closely associated with the types of failures encountered. It was also necessary to construct some special evaluation equipment for use in the examination and in the running of selected experiments. The effort did include a visit to the motor manufacturer, as originally anticipated.

As a result of a discussion with the Sponsor on May 8, 1962, regarding the results of our examination of selected parts of the 43 units, it was agreed that additional effort was needed in an attempt to effect a solution to the problems with the 230-volt drilling units. As envisioned, the proposed effort was to consist of the following activities:

(1) The 43 units were to be reassembled as nearly as possible in their original condition.

(2) Through discussions with the motor manufacturer, a maximum motor-case temperature was to be established for the motor that was to be used in determining when to terminate subsequent running tests.

(3) No-load tests were to be run on each unit to determine the time required to reach the established temperature.

(4) Running tests under full load, which was to be imposed by loading each unit until its speed was reduced by 20 per cent, were to be conducted to determine the time for each unit to reach the established temperature.

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(5) The data from the running tests and the part examinations were to be studied in detail and discussed with the motor manufacturer and the Sponsor.

(6) Tests were to be made with one or two typical drilling units to determine the effect of typical flows of water through the unit(s) on the time for the unit(s) to reach the established temperature under the no-load and full-load conditions.

(7) Based on this effort, a report was to be prepared incorporating our recommendations concerning possible design changes, manufacturing comments, and inspection procedures which would reduce greatly the number of unsatisfactory 230-volt drilling units to be expected from subsequent commercial-fabrication efforts.

Work Order No. 9, Task Order No. 9, was subsequently undertaken to accomplish these seven objectives. Because the nature of the recommendations to be evolved was not clear, the effort did not include the modification of any units or the evaluation of any modified units by us. It was agreed that, should such an effort subsequently become desirable, it would be considered at the appropriate time. Accordingly, when it appeared that 12 of the 43 units could be modified sufficiently to permit limited field operation, Task Order No. 20 was undertaken, on June 22, 1962, to accomplish this work. The modifications and the evaluation of the modified units are described in the "Summary Letter Report on Task Order No. 20", dated September 20, 1962.

SUMMARY

The 43 230-volt drilling units were inspected for mechanical and electrical defects which might result in premature failure. Each unit was then reassembled and operated without load and without water for 20 minutes. Six units did not start. Two units failed during the no-load test. The motor-case temperatures of the 35 units which operated ranged from 105 to 125 F; the maximum allowable temperature of 130 F was not reached by any of the units.

On the basis of discussions with the motor manufacturer and laboratory tests, it was determined that the motors were fully loaded when their speeds were reduced to 1,800 RPM; this was lower than the speed obtained by a 20 per cent reduction, that was originally believed to correspond to full load. The 35 units were operated at speeds of 2,600, 2,400, 2,200, 2,000, and 1,800 RPM, without water. The horsepower delivered was determined for each unit at each speed. Two units failed during these tests. The remaining 33 units were operated at 1,800 RPM for 20 minutes, or until the motor-case temperature reached 130 F. Three additional units failed during these tests; eight units operated for 20 minutes without reaching 130 F (two of these units delivering reduced horsepower because of bad armatures); the remaining units reached 130 F in time periods ranging from 10 to 18 minutes.

Tests with selected drilling units showed that the 230-volt motor did not overheat when operated in a no-load condition. Under full load, the 230-volt unit remained sufficiently cool when water flowed through the armature at the rate of 1 quart per hour; this rate is less than that needed for drilling with diamond drills.

Further, four 115-volt drilling units, supplied to us for comparison with the 230-volt units, were subjected to the same inspection and running tests as the 230-volt units. The results of this work were discussed in detail with the motor manufacturer. Typical 115- and 230-volt motors were examined and tested by the motor manufacturer. No failures occurred in the 115-volt units during any of the tests.

CONCLUSIONS

Because our understanding of the 230-volt units was helped significantly by the 1- and 50-hour full-load running tests conducted under Task Order No. 20, the conclusions and recommendations presented in this report are based on that work as well as upon the work done under Work Orders Nos. 6 and 9, Task Order No. 9. The conclusions are categorized under three headings: design, manufacture, and inspection.

Design

(1) Properly manufactured and installed in the drill housing, the 230-volt motor can deliver from 0.08 to 0.09 horsepower to the drill bit for at least 50 hours if water is passed through the armature at the rate of 1 quart per hour, and the motor is operated at 1,800 RPM.

(2) Because of the fine wire used, of necessity, in the armature needed for this application, the armature is susceptible to damage at several stages of manufacture. It is also susceptible to damage from

overloading resulting from motor stalling or operation at speeds of less than 1,800 RPM.

(3) The configuration of the motor brushes apparently increases the possibility of armature failure significantly.

(4) Less-than-good workmanship relative to wiring the drilling units results in susceptibility to armature and rectifier failure because of "shorts".

(5) The susceptibility of the sheet-metal rectifier shield to denting is a source of failure because of "shorts" in the rectifier wiring.

(6) The rear O-ring seal represents a possible source of failure stemming from water leakage into the armature. This possibility becomes greater as the O-ring deteriorates due to the effects of heat and age.

(7) Because the metering valve in the drilling-unit handle is difficult to adjust, the water supply to the drill can be accidentally shut off, thus resulting in overheating and failure of the motor.

Manufacture

(1) Because similar manufacturing errors and omissions were observed in the drilling units made by the two commercial fabricators, it is concluded that the quality of workmanship required for the drilling units

is better than that normally provided by the Sponsor's contractors.

(2) The armature, brushes, rectifier wiring, motor wiring, and rear O-ring seal are particularly susceptible to damage or improper installation during manufacture.

(3) Our re-examination of the necessary manufacturing operations does not indicate any unusually severe requirements. This apparently is substantiated by the absence of complaints or comments from the two commercial fabricators.

Inspection

(1) The inspection procedures set up in connection with the manufacture of these drilling units and implemented by the two commercial fabricators allowed units to pass with features which in some instances caused immediate failure, and in other instances were certain or extremely likely to cause premature failure ultimately. In many cases, it was difficult to estimate the probability of failure stemming from certain manufacturing inaccuracies.

RECOMMENDATIONS

It has been about five years since the basic design of the drilling unit was established. While a few carefully prepared units were originally evaluated extensively by the Sponsor, significant design modifications were subsequently incorporated that apparently were not evaluated extensively. In addition, as with many of the Sponsor's design problems, it has been especially difficult to specify in detail the operational requirements for the drilling unit. As a result, it is difficult to define those features of the presently available 115- and 230-volt drilling units that are satisfactory or unsatisfactory. It is particularly difficult to decide which features of these units could be changed, and to what extent, in order to provide for more satisfactory over-all operation. In view of the problems and of the conclusions presented above, the following recommendations are made relative to providing for the supply of improved 230-volt drilling units to the field:

(1) The most pressing need is for a re-examination of the limits previously established for important operational features of the drilling unit. Typical features are operating noise, weight, size, duration of operation, frequency of operation, expected service life, operator skill, reliability, repairability, cost, and ruggedness. It is recommended that the limits for these and other selected features be re-established on the basis of information obtained from taking the following steps:

(a) The present Sponsor's technical representative, a former operator, should operate a modified 230-volt drilling unit (from the Task Order No. 20 effort) on 50-cycle current under a variety of drilling conditions with what he, on the basis of his operator experience, considers to be the maximum amount of reasonable care. If the unit is not satisfactory, no modified 230-volt units should be shipped to the field. If the unit performs satisfactorily, it and the remaining 11 modified units should be shipped to field users who can be relied upon to feed back accurate descriptions of the performance of the units under service conditions. If arrangements cannot be made for such feedback, it is recommended that these units not be sent to the field.

(b) The present Sponsor's technical representative should operate a 115-volt unit on 50-cycle current with what he considers to be only a moderate amount of care. If, as expected, the unit performs satisfactorily, it is recommended that a program be undertaken immediately to modify a few 115-volt units in the same manner as the 230-volt units were modified under Task Order No. 20 and that portable transformers be provided so that the units could be operated on 230-volt current also. It is recommended that these units be sent to the field under the same conditions as described in (a) above.

(c) If the present Sponsor's technical representative does not believe that either the presently available

115- or 230-volt drilling units are satisfactory for field use, then every effort should be made to locate one each of the original 115- and 230-volt prototype drilling units which had been carefully fabricated in our laboratory under Task Order No. O. These units supply 25 per cent more horsepower than do the presently available units and may perform satisfactorily. In view of their age, they should be returned to us for examination and renovation, and then should be evaluated by the present Sponsor's technical representative. If both or one of the units is judged to be satisfactory, the remaining 115- and 230-volt prototype units should be located, renovated, and sent to carefully selected field locations for evaluation, and subsequent feedback of performance information.

(2) If the transformer-equipped 115-volt units are found to be satisfactory by field operators, a program should be undertaken to convert the presently available 230-volt units by equipping them with 115-volt fields and armatures, and to provide an appropriate number of portable transformers. This would provide the field operators with units for reliable 115- and 230-volt operation until a significant improvement could be effected. Such an improvement might require two years to accomplish.

(3) It is recommended that a paper study be initiated as soon as possible to determine what improvements could be made in reliability and ruggedness by using a larger motor frame. This design change has been recommended by the motor manufacturer as the only means of greatly improving these two features. However, the advantages of such a development must be weighed against an increase in the size and weight of the drilling unit and the probable obsolescence of the presently available drilling units, and drilling-kit containers. This program would serve two purposes: (a) it would provide for possible eventual improvement of the present design, and (b) it would serve as a back-stop against the possibility that none of the units developed to date is satisfactory. In view of our familiarity with the entire problem and the need for objectivity in the consideration of different motor manufacturers and different commercial drill housings, we would particularly appreciate being considered for such a program.

(4) For the future fabrication of drilling units, it is recommended that above-average-quality workmanship be specified and that the components, subassemblies, and assemblies be subjected to 100 per cent inspection.

ENGINEERING ACTIVITY

The engineering activity on the two programs consisted of the examination of the mechanical and electrical components of 43 230-volt drilling units and the evaluation of these units under selected load conditions. The results of this effort are discussed below under the headings "Mechanical and Electrical Inspection", and "Operational Evaluation".

In order for the test results to have full meaning, it is believed that they should be considered in the light of the important developments which led to the manufacture of the units of interest. Appendixes 1 through 12 of this report contain summaries of the various programs related to the drilling equipment. In the following section titled "Background Developments", the highlights of the previous work and certain efforts carried out by the Sponsor are summarized.

Background Developments

This discussion is presented in terms of the major components of the drilling units and associated items, namely, the drills, the motor, the motor case, and the flushing-medium supply. Prior to a discussion of these, however, the general developmental history of the drilling unit is outlined.

General Discussion

The 115- and 230-volt drilling units and the associated components supplied in the specialized drilling kits represent unique drilling mechanisms. Equipment is available commercially to drill with water or air flushing for chip removal, but in such equipment the flushing medium is supplied through an adapter which is attached to the front of the drilling unit. To our knowledge, the provision for water to flow through the drilling-unit case and the motor armature has not been made available in a commercial product. This arrangement and that incorporated in some of the accessories were evolved during several years of developmental effort involving work by our organization and, to some extent, by others.

The drilling-unit development was initiated in 1955 as a part of Research Order No. 21. It was originally believed desirable for drilling to be performed as a part of a general operation to place wires in selected locations underground and in buildings. As the work progressed, however, it became apparent that the horsepower needed to provide for placing wire in the ground was much more than that needed for drilling holes through masonry walls to provide for passage of the wire. Consequently, it was decided that separate drilling equipment should be developed. During that program, the Type 1 Prototype Drilling Unit was evolved. It consisted of the following: a 1,725-RPM, 1/4-horsepower electric motor; a 5-foot-long flexible shaft; a manually pressurized 1-quart-capacity water tank and a CO_2 cylinder for chip flushing; a drill-handle assembly which joined the drill to the flexible shaft and to the chip-flushing medium; a loading assembly to facilitate the application of appropriate loads to the drills; and 5/16-inch-diameter carbide and diamond core drills. The complete unit weighed 30 pounds.

In 1956, Research Order No. 30 was undertaken to reduce the weight of the drilling equipment by making the electric motor integral with the drilling head. During that program, it was determined that satisfactory drilling rates could be attained with less power, namely, with 1/10 horsepower. That program resulted in the incorporation of a 1/8-horsepower motor in a standard housing for a commercial 1/3-horsepower drill. A kit called the Type 2 Prototype Drilling Kit was assembled. It consisted of the following: a carrying bag, a 20-foot length of electrical connecting wire, a rectifier, a drilling unit, a water tank, a CO_2 cylinder, a dust and water collector, the necessary tubing, and three 5/16-inch-diameter diamond drills. The entire kit weighed 15 pounds.

In 1957, under Work Order No. XI, Task Order No. A, 3/16-inch-diameter diamond-impregnated drills were evaluated and the water swivel was changed from the front of the drill housing to the back, to simplify the construction of the drilling unit. Under Task Order No. O, also conducted in 1957, the design of the drilling unit was refined further. Also, 12 drilling kits were fabricated, and specifications, drawings, and an operator's manual for the kits were prepared. A part of the design refinement consisted of the inclusion of the rectifier unit within the drilling-unit housing. Although the drilling units prepared under Task Order No. O incorporated 1/8-horsepower motors, laboratory tests under this program indicated that a 1/10-horsepower motor constructed on the same motor frame would probably be satisfactory. Consequently, the summary report on the Task Order No. O program contained the recommendation that the 1/10-horsepower motor with improved insulation should be considered in connection with any future production of the units.

It is our understanding that some of the drilling units prepared under Task Order No. O were operated extensively by the Sponsor. Some time subsequently, arrangements were made by the Sponsor for the manufacture, by a commercial fabricator, of a number of drilling kits. Apparently, as a part of that procurement effort, certain modifications were incorporated in the design of the drilling unit. These included the use of an O-ring seal at the rear end of the armature shaft instead of a carbon-face seal, the use of chokes in the rectifier assembly, and the use of valves in the drilling-unit handle to facilitate control of the flow of water. Apparently, the units resulting from this procurement effort were not evaluated extensively.

In the past year or so, the Sponsor contracted for the fabrication of more drilling kits by a different commercial fabricator. During this second fabrication effort, a number of manufacturing problems were encountered, particularly with the 230-volt drilling units. In addition, some reports were received by the Sponsor concerning the malfunctioning of the 230-volt units. These problems resulted in the initiation of the programs under Work Orders Nos. 6 and 9, Task Order No. 9.

Drills

The nature of the drilling equipment needed for the service application of interest is influenced largely by the type of drill used. In connection with the original work under Research Order No. 21, it was understood that the major objective was to provide for making holes in masonry materials as rapidly as possible. Laboratory tests showed that most of the masonry materials could be penetrated best by carbide-tipped drills using air or water for chip removal. It was found that satisfactory holes could be made through 30-inch-thick material using 5/16-inch-diameter carbide-tipped drills. Unfortunately, however, the noise resulting from the use of this type of drill on masonry materials was considered to be unacceptable for many of the operations being contemplated by the Sponsor and his associates.

Consequently, during the developmental programs, drills with diamond-impregnated tips were also evaluated. It was found that although the drilling rate was significantly reduced, the noise level associated with the use of diamond drills was acceptable; further, the noise level involved with diamond core drills was particularly attractive. On the basis of this and similar work, the Sponsor standardized on the use of 3/8- and 1-inch-diameter diamond core drills for the drilling kits. One carbide-tipped drill was included in the kit, for use in selected applications.

Laboratory tests with the drills showed that satisfactory drilling rates could be attained with 1/10 horsepower. Also, for satisfactory operation in most materials, water flushing had to be used with the diamond core drills.

Motor

As indicated in Appendix 1, the original motor used was a 1/4-horsepower unit. In our work, it was found possible to burn up the 1/4-horsepower motor when the 5/16-inch-diameter carbide drills were used. However, consideration of the total weight of the drilling equipment developed under Research Order No. 21 showed that the drilling components were not readily portable. Thus, under Research Order No. 30, considerable work was done to investigate the possibilities of reducing the motor size. This and subsequent effort resulted in the selection of a 2,800-RPM, 1/10-horsepower shunt-wound DC motor. The major factors involved in this selection are discussed below.

Noise. A low noise level has always been a major requirement relative to the drilling equipment. Extensive discussions with motor manufacturers resulted in the conclusion that a drilling unit with a satisfactory noise level could not contain reduction gearing. Experience with the diamond drills showed that these drills would not operate satisfactorily at speeds greater than 4,000 RPM. Consequently, these two facts necessitated the evolution of a drilling unit with direct drive and operating at speeds of 4,000 RPM or lower.

Laboratory tests with selected motors showed that the noise from the brushes increased significantly at motor speeds greater than 3,000 RPM. Evaluation of the different noise levels by the Sponsor resulted in the decision that the motor should operate at a speed of less than 3,000 RPM.

The 1/8-horsepower drilling units prepared under Task Order No. 0 had a no-load speed of approximately 3,800 RPM. The Sponsor's evaluation of these units was the major factor which led to the laboratory evaluation of 1/10-horsepower motors and the subsequent recommendation of consideration of 1/10-horsepower motors for the then-future production of drilling units. A significant difference between the 1/8- and the 1/10-horsepower motors was the size of the wire and the number of turns used in the armature. The use of smaller wire and a larger number of turns resulted in the 1/10-horsepower motor having a no-load speed of approximately 2,800 RPM.

Motor Type. The selection of a shunt-wound DC motor was based primarily on the required no-load speed of approximately 3,000 RPM and the necessary small size and low weight. This decision was reached via discussions with Robbins and Myers Inc., a major manufacturer of fractional-horsepower motors, and with our electrical engineering personnel. The availability of small, lightweight rectifying devices was also a factor in the selection of this type of motor. The electrical principles leading to this selection are too involved to be presented in this report. In summary, it can be concluded that at the time the decision was made, the selection of any other type of motor would have resulted either in a much heavier unit, or in the provision of horsepower and speed insufficient to accomplish satisfactory drilling with diamond-impregnated drills.

Size and Weight. The size and weight of the motor used were influenced primarily by the horsepower required, the duty cycle expected, and the available motor frame size. As described previously, laboratory tests had shown that satisfactory drilling could be accomplished with power units providing of the order of 1/10 to 1/8 horsepower. Discussions with Robbins and Myers revealed that a marginal 1/8-horsepower motor could be wound on a certain frame size which was standard in their operations. This motor was expected to be marginal because its continuous operation at 1/8 horsepower would result in overheating and subsequent failure of the insulation. However, in view of the expected duty cycle for the drilling unit, it appeared that this marginal motor might be satisfactory; the Sponsor had estimated that the unit would not be used under full load for periods longer than 20 minutes. Furthermore, the passage of water through the armature shaft made for a unique and extremely effective source of motor cooling; the water had to be provided anyway, because the diamond drills could not be used satisfactorily without it. Evaluation of the 1/8-horsepower motors which were subsequently fabricated verified these considerations. (Incidentally, since that time, reports have been received relative to the use, by other designers, of water cooling to reduce a motor size significantly below that normally considered to be satisfactory.)

The consideration of the 1/8-horsepower-motor-frame size in connection with a 1/10-horsepower unit represented the potential use of all of the latitude provided by the short-duty cycle and water cooling; it was known that the 1/10-horsepower motor would heat more rapidly than the 1/8-horsepower motor, but it was hoped that the short-duty cycle and water cooling would make it possible to use the 1/10-horsepower motor satisfactorily. Laboratory tests substantiated this estimate, but it was recommended that the use of high-temperature insulation be considered in connection with any then-future production of units.

The 1/8- and 1/10-horsepower motors described above were wound on a particular standard motor frame. Robbins and Myers have indicated that the overheating problem can be alleviated only by using the next larger motor frame. This would result in a significant increase in the size and weight of the drilling unit. Depending on the definition of the duty cycle, ruggedness, and reliability required by the Sponsor in this drilling unit, these increases may or may not be tolerable.

Motor Case

Any motor frame which is standard for a motor manufacturer is probably so because it is part of a commercial item which is produced in large numbers. Further, the selection and application of a standard motor generally provide the opportunity of using a standard motor housing. In regard to the 1/8- and 1/10-horsepower motors, a standard 1/3-horsepower hand-drill housing was available and was incorporated in the design. The use of this production item as part of the specialized drilling units saved a significant sum of money.

If in the future the motor frame size used for the drilling unit is increased, it is strongly recommended that the new motor frame be selected in conjunction with the selection of a commercially available hand-drill housing.

Flushing-Medium Supply

As described previously, air was used in the early tests to flush the chips during operations with carbide drills. Because air or CO_2 cannot be used satisfactorily with diamond drills, the Sponsor's decision to use diamond drills most of the time in the field drilling operations significantly eliminated the need for providing for air or CO_2 flushing. In fact, at the present time, drilling under conditions where water is not required can probably be accomplished best by the periodic removal of the drill from the hole and subsequent flushing out of the hole with the squeeze bulb included in the drilling kit.

Water is required to flush the diamond drills. Most diamond drills are designed, tested, and marketed by the manufacturer for use with water as the flushing medium. The amount of water required varies with the type of drill and the drilling rate desired. The commercially available hand-pressurized 1-quart container provided with the drilling kit was selected early in the developmental programs as a temporary measure. However, the low cost of this item and its simplicity are extremely attractive. Furthermore, the rate of water usage results in the water-filled tank being satisfactory for approximately 20 minutes of operation. Consequently, until a better definition is available concerning the required duty cycle of the drilling equipment, this tank will probably be satisfactory.

Two programs were undertaken to investigate the possibilities of supplying a simple pumping arrangement for use with an open container for the water. This work was done under Work Order No. IV, Task Order No. CC, and under Task Order No. II. The major problems encountered were the low rate of flow, the high pressure considered to be necessary, and the need for a second motor to drive the pump. It was not possible under these programs to develop an arrangement which appeared to be more satisfactory than the hand-pressurized tank.

Mechanical and Electrical Inspection

According to reports from the manufacturer and from the field, the problems with the recently manufactured 230-volt drilling units appeared to be related to the motors. Failure in most cases stemmed from a failed armature. Because it was not clear whether the failures were resulting from problems of manufacturing or inadequacies of design, the first step in the investigation conducted under Work Orders Nos. 6 and 9, Task Order No. 9, was an inspection of those parts which might be involved in a motor failure. A visual check was conducted, and measurements were made, for example, of the no-load shaft torque. In addition, equipment was rigged and used to test the electrical continuity of the motor fields and armatures. These mechanical and electrical checks were performed on all 43 drilling units.

Table 1 lists the information obtained from the mechanical and electrical checks. In the table, an "X" indicates either certain failure or probable failure during the first few hours of operation, and a question mark ("?") indicates possible future failure. The results of this inspection are summarized below:

Table 1. Results of Mechanical and Electrical Inspection

Drilling-Unit No.	Model No.	Mfr.	Shaft Torque, lb	Outside Appearance	Brushes and Commutator	Rectifier Holder	Front Bearing	Front O-Ring Seal	Fan	Armature	Rear Bearing	Rear O-Ring Seal	Rear-Bearing Housing	Rectifier Wiring	Armature Windings	Commutator	Field	Missing Parts	Remarks
1	UVH-2B	WTA	.12	OK	X	OK	?	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	Improperly installed brush; spring bent double in holder
2	-2B	WTA	.11	OK	OK	OK	?	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
3	-2B	WTA	.075	OK	OK	?	?	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
4	-2B	WTA	.080	OK	X	OK	?	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	Upper brush to field wire rubbing on armature winding
5	-1B	AMF	-	?	X	X	?	OK	OK	OK	OK	X	OK	OK	OK	OK	OK	?	(1)
6	UVH-1B	AMF	.070	OK	OK	OK	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	OK	?	Thrust washers missing on front bearing
7	-1B	AMF	.105	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
8	-2B	WTA	.10	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
9	-2B	WTA	.11	OK	OK	?	?	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
10	-2B	WTA	.09	?	OK	?	?	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	Example of choke burning insulation
11	UVH-2B	AMF	.115	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	X	-	Field resistance about 3 times greater than should be
12	-2B	AMF	.122	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
13	-2B	AMF	.085	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	?	Piston button missing
14	-2B	AMF	.082	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
15	-1B	AMF	-	OK	?	X	?	OK	OK	OK	?	X	OK	OK	OK	OK	OK	-	(2)
16	UVH-1B	AMF	.13	OK	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	X	OK	OK	-	Open winding in armature
17	-1B	AMF	.145	OK	OK	OK	OK	OK	OK	OK	?	X	OK	OK	OK	OK	OK	-	Rear O-ring seal sheared when shaft inserted
18	-2B	AMF	.132	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
19	-2B	AMF	.120	?	X	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	Brush holders in crooked
20	-2B	AMF	.135	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
21	UVH-2B	AMF	.108	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
22	-1B	AMF	.09	X	?	OK	OK	OK	OK	OK	?	OK	OK	X	OK	OK	OK	-	Choke shorting through front bearing shield
23	-1B	AMF	.55	?	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	X	OK	OK	?	(3)
24	-1B	AMF	.145	?	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	X	OK	OK	?	Open winding in armature; nut and lock washer on rear-bearing housing missing
25	-2B	WTA	.093	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	X	OK	OK	OK	-	Choke lead touching rectifier holder
26	UVH-2B	WTA	.082	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	X	OK	OK	OK	-	AC-DC connecting plugs touching (leads); thrust washer on front bearing in backwards
27	-2B	WTA	.125	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
28	-2B	WTA	.118	OK	OK	OK	?	?	OK	OK	OK	OK	OK	X	OK	OK	OK	-	Choke leads touching rectifier holder - shorting
29	-2B	WTA	.088	OK	OK	OK	?	?	OK	OK	OK	OK	OK	X	OK	OK	OK	-	Choke leads touching rectifier holder - shorting
30	-2B	WTA	.065	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
31	UVH-2B	WTA	.097	OK	OK	OK	?	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
32	-2B	WTA	.105	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
33	-2B	WTA	.105	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
34	-2B	AMF	.095	OK	OK	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	OK	-	-
35	-2B	AMF	.115	OK	OK	OK	OK	OK	?	OK	?	OK	OK	OK	OK	OK	OK	?	Piston button missing

Table 1. (Continued)

Drilling-Unit No.	Model No.	Mfr.	Shaft Torque, lb	Outside Appearance	Brushes and Commutator	Rectifier Holder	Front Bearing	Front O-Ring Seal	Fan	Armature	Rear Bearing	Rear O-Ring Seal	Rear-Bearing Housing	Rectifier Wiring	Armature Windings	Commutator	Field	Missing Parts	Remarks
36	UVH-2B	AMF	.145	OK	OK	OK	OK	OK	?	OK	OK	OK	OK	OK	OK	OK	OK	-	-
37	-2B	AMF	.095	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
38	-2B	AMF	.090	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	-	-
39	-2B	WTA	Motor shaft turned over with such difficulty that it was doubtful that it would start; did not disassemble.																
40	-2B	WTA	.090	OK	OK	OK	OK	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
41	UVH-2B	WTA	.125	OK	X	OK	OK	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	Improperly installed brush; spring bent double in holder
42	-2B	WTA	.085	OK	OK	OK	?	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-
43	-2B	WTA	.075	OK	OK	OK	?	?	OK	OK	OK	OK	OK	?	OK	OK	OK	-	-

Note: "X" denotes that the condition of the item was such that certain or probable failure of the unit was indicated.
"?" denotes that the condition of the item was such that possible failure of the unit was indicated.

(1) Drilling Unit No. 5: Front bearing housing dented. Tape found over part of one motor brush. No hole to release adapter shaft. Nut and lock washer for holding rear bearing housing to motor case missing. Rear O-ring seal sheared when armature shaft inserted.
(2) Drilling Unit No. 15: No hole to release adapter shaft. Rear O-ring seal sheared when armature shaft inserted.
(3) Drilling Unit No. 23: Open winding in armature. Armature shaft tight (freed shaft by loosening front bearing shield). Front bearing fairly "rough". Thrust washer in backwards. Choke possibly shorting where shield bent and touching. Nut and lock washer for holding rear bearing housing to motor case missing.

(1) In 19 drilling units, choke-lead wires were found to be touching the plastic on the connecting posts of the housing. Heat from the choke wiring might burn through the plastic, thus causing a short to the posts and failure of the unit.

(2) In two instances, motors were found with the brush wiring rubbing on the armature or commutator. When the insulation wiring had worn off, a short would result, thus causing failure of the drilling unit.

(3) In three instances, the motor had associated bare wires touching the metal of the housing. This condition would cause either a dead short or the electrical charging of the motor case that could result in hazard to the operator.

(4) In four instances, the brushes were improperly installed such that stoppage or failure of the drilling unit after a period of time was highly probable.

(5) In three instances, the rear O-ring seal had been sheared when the armature was inserted in the housing. The resultant water leakage would cause failure of the drilling unit.

(6) In two instances, parts were missing from the motor. This condition might cause failure.

(7) In eight instances, the Bakelite part of the rectifier holder was cracked at the screw holes. While this defect would not result in early failure, it might eventually cause malfunctioning of the drilling unit.

(8) In eight instances, the sheet-metal shield was bent. In two instances, these dents resulted in shorts relative to the rectifier wiring.

(9) Three armatures had open windings, and one motor field showed excessive resistance.

Operational Evaluation

After the above-described inspection was completed, the 43 drilling units were reassembled as nearly as possible in their original condition preparatory to conducting the running tests. Discussions with Robbins and Myers indicated that any running tests performed should be terminated when the motor-case temperature reached 130 F. The choice of this temperature was substantiated by the failure of one drilling unit in a running test conducted in our laboratory at 1,800 RPM and without water; at the time the armature failed, the case temperature was about 135 F.

No-Load Tests

Because excessive motor heating was expected to be a cause of failure of the 230-volt drilling units, the first running test consisted of operating each unit with no load and without water, to determine whether it would overheat under these conditions and how long it would take to do so. The results would thus give an indication of the care which the operator would have to exert when running the unit without load and without water.

The motor-case temperatures of the units which operated ranged from 105 to 125 F. None of the units reached a motor-case temperature of 130 F during 20 minutes of operation. This showed that overheating is not a problem in the no-load condition. However, as shown in Table 2, six of the units failed to start (Nos. 5, 8, 11, 22, 24, and 29) and two of the units failed (Nos. 6 and 18) during the no-load tests.

The no-load RPM of the units is of interest because of the implications concerning reproducibility. The no-load RPM ranged from 2,790 to 3,165. According to NEMA standards a no-load speed of ±10 per cent is acceptable. Thus, the motors of these units fell well within the acceptable variation, although the median value for RPM was slightly higher than the original design value of 2,800 RPM.

Full-Load Tests

It was originally believed that the motors would be fully loaded when the no-load speed had been reduced by 20 per cent; this condition is standard with shunt-wound DC motors. However, discussion with the motor manufacturer revealed that this particular motor was designed to be operated at 1,800 RPM. Table 2 shows the horsepower delivered at speeds of 2,600, 2,400, 2,200, 2,000, and 1,800 RPM; in these tests, the load was applied by means of a prony brake. Two units (Nos. 4 and 10) failed during these tests. Two of the units with bad armatures (Nos. 16 and 23) ran satisfactorily, but did not deliver horsepower comparable to the other units. The horsepower from the remaining units at 1,800 RPM ranged from .072 to .093. The extent to which these values were less than the rated 1/10 horsepower is explained by the variation in motor components and by the power required to overcome the friction in the rear O-ring seal and in the two antifriction bearings.

Table 2. Results of No-Load and Full-Load Tests

Drilling-Unit No.	No-Load Speed, RPM	Load Tests: Horsepower at Indicated RPM: 2,600	2,400	2,200	2,000	1,800	Motor-Case Temp., F	Shaft Temp., F	Time, min	Remarks
1	3,015	.036	.062	.079	.090	.093	125	302	10	--
2	3,070	.039	.057	.077	.086	.088	130	300	10	--
3	2,990	.039	.064	.079	.098	.079	120	275	10	--
4	2,865	.028	.055	--	--	--	--	--	--	Failed
5	--	--	--	--	--	--	--	--	--	Failed to start
6	--	--	--	--	--	--	--	--	--	Failed in no-load check
7	3,165	.026	.060	.094	.086	.072	130	300	10	--
8	--	--	--	--	--	--	--	--	--	Failed to start
9	2,890	.023	.021	.035	.038	.079	130	294	15	--
10	2,880	--	--	--	--	--	--	--	--	Failed - shorted
11	--	--	--	--	--	--	--	--	--	Failed to start
12	3,040	.036	.048	.099	.098	.085	110	278	15	--
13	3,075	.033	.055	.088	.092	.081	130	330	13	--
14	3,030	.044	.060	.072	.086	.088	90	190	2	Failed
15	3,130	.049	.064	.083	.082	.090	130	328	16	--
16	2,900	.019	.030	.044	.052	.054	115	230	20	Armature bad
17	2,865	.020	.050	.070	.088	.084	130	318	13	--
18	--	--	--	--	--	--	--	--	--	Failed in no-load check

Table 2. (Continued)

Drilling-Unit No.	No-Load Speed, RPM	Load Tests: Horsepower at Indicated RPM 2,600	2,400	2,200	2,000	1,800	Motor-Case Temp., F	Shaft Temp., F	Time, min	Remarks
19	3,050	.026	.052	.059	.052	.080	125	338	20	--
20	3,020	.044	.028	.081	.090	.090	115	295	20	--
21	2,990	.044	.064	.090	.094	.093	123	323	20	--
22	--	--	--	--	--	--	--	--	--	Failed to start
23	2,880	.031	.029	.044	.050	.050	103	109	20	Armature bad
24	--	--	--	--	--	--	--	--	--	Failed to start
25	3,050	.033	.060	.079	.086	.075	113	310	10	Failed
26	2,790	.026	.038	.064	.080	.079	130	313	16	--
27	2,910	.030	.050	.072	.088	.086	130	300	17	--
28	2,870	.031	.040	.077	.090	.090	127	300	20	--
29	--	--	--	--	--	--	--	--	--	Failed to start
30	2,915	.026	.031	.075	.084	.086	110	262	13	Failed
31	2,860	.026	.043	.061	.096	.073	125	297	20	--
32	2,835	.026	.043	.070	.088	.083	125	290	20	--
33	2,925	.026	.050	.072	.088	.083	130	310	18	--
34	2,920	.036	.060	.081	.090	.086	130	302	13	--
35	2,945	.031	.052	.070	.076	.079	130	290	15	--
36	2,983	.046	.048	.077	.086	.075	130	317	17	--

Table 2. (Continued)

Drilling-Unit No.	No-Load Speed, RPM	Load Tests								
		Horsepower at Indicated RPM					Motor-Case Temp., F	Shaft Temp., F	Time, min	Remarks
		2,600	2,400	2,200	2,000	1,800				
37	2,935	.039	.038	.072	.084	.086	130	325	14	--
38	2,990	.041	.060	.074	.090	.075	130	303	15	--
39	2,910	.033	.055	.081	.094	.088	130	310	15	--
40	2,820	.031	.067	.077	.105	.082	130	328	16	--
41	2,930	.033	.043	.070	.090	.084	130	290	13	--
42	2,855	.036	.045	.074	.100	.084	130	295	13	--
43	3,000	.046	.066	.076	.100	.090	130	297	14	--

Notes: (1) Water was not passed through the units during these tests.
(2) In the load tests, the load was applied by means of a prony brake.

The remaining 33 units (including the two with bad armatures) were then operated without water at 1,800 RPM for 20 minutes or until the motor-case temperature reached 130 F. This test was designed to explore the potential problem of overheating if for some reason water was not flowing while the drilling-unit motor was energized. As shown in Table 2, three units (Nos. 14, 25, and 30) failed during this test. Eight units operated for 20 minutes without reaching 130 F. Of these, six units delivered adequate horsepower; the two units which delivered low horsepower were those which had been characterized above as having bad armatures. The remaining units reached 130 F in times ranging from 10 to 18 minutes. These tests showed that the 230-volt drilling unit should not be operated at full load without water for longer than 10 minutes because of the resultant overheating and premature failure.

A summary of the causes of motor failure other than overheating is given in Table 3. It can be seen that motor failure can be caused by a variety of factors in addition to overheating.

Effect of Water Cooling

Since water has to be used in order to achieve satisfactory operation with diamond drills, tests were conducted to determine whether the use of water in the normal drilling operation would also serve to eliminate the danger of overheating. The no-load tests had shown that there was no danger of overheating if the unit was not loaded; one unit was run dry for 24 hours without overheating.

A drilling unit was operated at 1,800 RPM with a minimum flow rate of water for diamond drilling, namely, 1 quart per hour; the normal flow

Table 3. Summary of Causes of Motor Failure Other Than Overheating

Drilling-Unit No.	Mfr.	When Failure Occurred	Cause of Failure
4	WTA	Load check	Short - wire from brush to field was rubbing armature
5	AMF	Turn-on check	Rear O-ring seal was binding shaft; tape over motor brush
6	AMF	No-load check	Armature was rubbing field
8	WTA	Turn-on check	Short - connecting post to choke (fuse blew)
10	WTA	Load check	Short - lead-in wire to ground; may have had bad rectifier
11	AMF	Turn-on check	Bad field (fuse blew)
14	AMF	Load check	Bad armature (open) and bad rear O-ring seal (fuse blew)
18	AMF	No-load check	Undetermined (fuse blew)
22	AMF	Turn-on check	Short - choke to front bearing shield (fuse blew)
24	AMF	Turn-on check	Rear O-ring seal melted; may have had bad rectifier (fuse blew)
25	WTA	Load check	Bad armature (open) and bad rear O-ring seal (fuse blew)
29	WTA	Turn-on check	Short - choke to rectifier holder (fuse blew)
30	WTA	Load check	Bad armature (open) and bad rear O-ring seal (fuse blew)

rate is about 3 quarts per hour. This unit was run for 24 hours; the maximum motor-case temperature reached was 124 F. This test showed that overheating is not a problem with the 230-volt drilling unit if water is supplied in normal fashion at a rate which is minimal or normal for diamond drilling.

Effect of Overloading

During our operations with the 230-volt drilling units, however, it became apparent that the armature is susceptible to failure as a result of stalling of the motor or reduction of its speed significantly below 1,800 RPM. These conditions can be expected to result in the field, particularly with the use of the 1-inch-diameter diamond core drill. For example, the friction of the drill tubing against the core as the 1-inch-diameter hole is drilled to depths greater than 4 inches or more represents one likely cause of stalling or overloading. This type of condition results in excessive current flowing to the armature, and this, in turn, causes armature failure. However, insufficient data have been obtained to define how much overloading can be tolerated by the 230-volt drilling unit.

Inspection and Testing of 115-Volt Drilling Units

Four drilling kits incorporating 115-volt drilling units were furnished by the Sponsor for a cursory comparison of the drilling units with the 230-volt units. The 115-volt units were subjected to the same inspection and running tests as indicated above for the 230-volt units.

The results of the mechanical and electrical inspection were as follows:

(1) The Ohmite power line chokes were touching the plastic covers on the connecting posts on each of the four motors.

(2) The Bakelite part of the rectifier holder was cracked on two of the motors.

(3) One motor had a tight spot on the shaft (when the shaft was turned by hand). This condition stemmed from the screws which held the Bakelite part in the rectifier holder being so long that they "caught" on the thrust washer.

(4) The rear-bearing housing of one motor was damaged, apparently as a result of the shaft having been dropped on the housing during manufacture of the drilling unit.

In other regards, the components, including the armatures, fields, and commutators, were found to be satisfactory.

In the no-load running tests without water, the motor case temperatures were about the same as were noted for the 230-volt motors. However, in the load running tests, the case temperatures were low enough that the motors appeared to operate satisfactorily without water cooling. None of the 115-volt units failed during these tests.

Results of Manufacturer's Tests

The motor manufacturer offered to conduct tests with motors from the 115- and 230-volt drilling units to determine the relative rate of temperature rise in the motors. Units were provided and the tests were run.

As a result of this work, the motor manufacturer concluded that the 115-volt motor, when operated without water cooling, overheats significantly faster than is normally tolerated in commercial design practice. The effect of water cooling and of the estimated duty cycle on the motor was not a part of the consideration provided by the motor manufacturer.

Also, it was concluded that the 230-volt motor overheats significantly faster than the 115-volt unit. The wire used in the armature for the 230-volt motor is of standard size; nevertheless, because of the small diameter, it is susceptible to damage in various stages of manufacture. Without taking into account the effect of water cooling and of the estimated duty cycle, the motor manufacturer strongly recommended that a larger motor incorporating an armature wound with larger wire be used in this 230-volt application. On the basis of a preliminary discussion of the size of the motor and of the associated drilling-unit housing which might be satisfactory, it is estimated that the use of a larger motor would increase the total weight of the drilling kit by 5 to 10 pounds. Furthermore, in view of the larger size of such a motor, it appears probable that the present drilling-kit container (suitcase) would probably not "take" the larger drilling unit and would have to be declared obsolete.

APPENDIXES 1 THROUGH 12

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APPENDIX 1

RESEARCH ORDER NO. 21

The work under Research Order No. 21 was conducted from February 1, 1955, through July 31, 1956, and the detailed results are presented in the "Summary Report on Research Order No. 21", dated July 31, 1956. The original objective of Research Order No. 21 was the development of a gasoline-engine-driven trencher and of a rotary drilling unit which could be used interchangeably with the same power head. Such an implement was needed to facilitate laying wire approximately 36 inches below the surface of the earth and through masonry walls of 30-inch maximum thickness. The device was to be portable, relatively quiet, rapid in operation, and independent of a remote source of power.

As the work progressed, it became apparent that the power required for trenching was at least 20 times that required for drilling through masonry walls. For this reason two separately powered implements were developed. The trenching unit was powered by a 10-horsepower portable gasoline engine of the type used for chain saws. The drilling unit was designed so that it could be driven by an electric motor or by the power head of the trenching unit. Toward the end of the research period, the project scope was expanded to provide for the fabrication of three Type 1 Prototype Drilling Units, and subsequently of three Type 1 Prototype Trenching Units.

Detailed information regarding the trenching unit is not pertinent to this report.

The development of a drilling unit capable of penetrating 30-inch-thick masonry walls necessitated the construction of special laboratory test equipment. With this equipment, selected materials were drilled while measurements were made of the speed (RPM) of the drills, the axial load on the drills, the rate of drilling, and the power consumed. Tests with this equipment showed that all common building materials except marble and granite could be drilled at a rate of at least 3 inches per minute with a 3/4-inch-diameter carbide-tipped drill, air flushed for chip removal. Tests with different designs of commercial carbide drills, with air flushing used for chip removal, indicated that the performance of the various drills was substantially the same.

It soon became apparent that a significant reduction in power consumption and over-all weight could not be effected unless the diameter of the drill used was reduced. It was then found that the drill diameter could be reduced to 5/16 inch on a practical basis and that 30-inch-deep holes could be drilled with such relatively small drills. With a power supply of only 1/4 horsepower, drilling rates with a 5/16-inch-diameter drill increased considerably, even though the axial load on the drill was reduced. At this point in the development, water flushing was introduced, and a simple 5/16-inch-diameter arrowhead-type carbide drill was developed that was satisfactory for penetrating all of the common building materials except granite. Cursory tests made with diamond-impregnated core drills proved that granite also could be drilled, but no conclusions were reached concerning diamond drills.

Once it was learned that the drilling could be done with as little as 1/4 horsepower, it was decided that each drilling unit should have its own power supply. Because the drilling units were to be used in different parts of the world with different types of power supplies, it was believed that the units could be made most versatile by separating the motor from the drilling handle. With the drilling handle connected to the motor with a flexible shaft, almost any type of motor, with matching source of current, could be used satisfactorily. Several experimental units were designed and tested, and a prototype unit was evolved. This unit, called the Type 1 Prototype Drilling Unit, consisted of the following:

(1) A 1,725-RPM 1/4-horsepower electric motor

(2) A 5-foot-long flexible shaft

(3) A manually pressurized, 1-quart-capacity water tank and a CO_2 cylinder, for chip flushing

(4) A drill-handle assembly which joined the drill to the flexible shaft and to the chip-flushing medium

(5) A loading assembly to facilitate the application of appropriate loads to the drills

(6) Both carbide and diamond drills.

The complete unit, shown in Figures 1 and 2, weighed 30 pounds. Three of the Type 1 Prototype Drilling Units were transmitted to the Sponsor in March, 1956, along with colored motion pictures and slides depicting the proper operation of the unit.

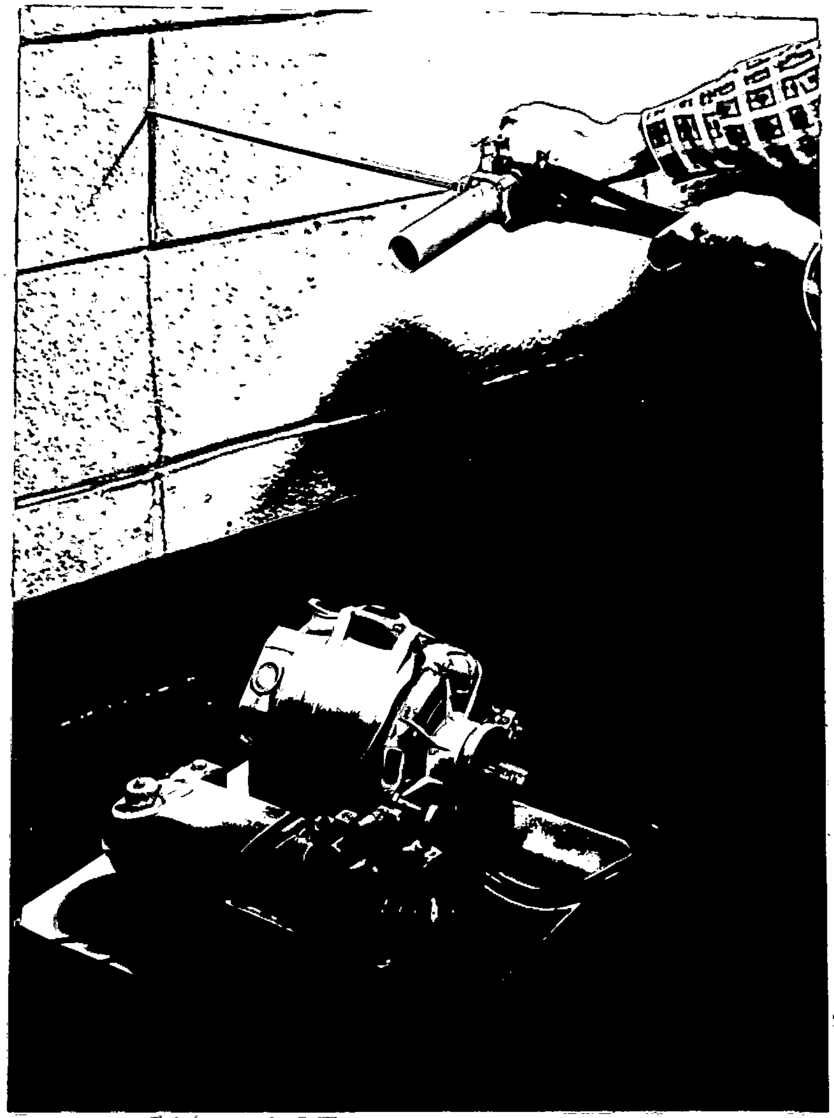

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Figure 1. The Type 1 Prototype Drilling Unit

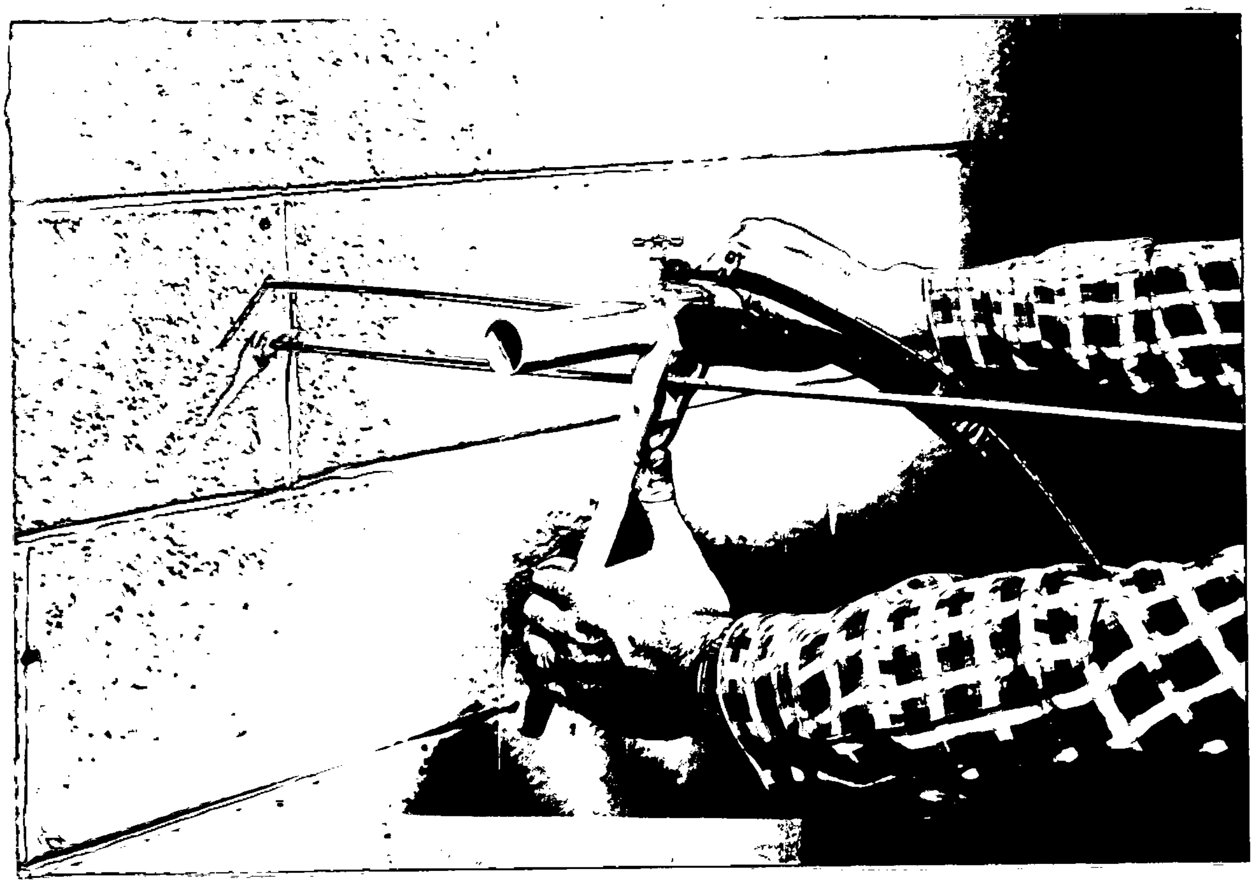

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Figure 2. The Loading Assembly of the Type 1 Prototype Drilling Unit During Operation

APPENDIX 2

RESEARCH ORDER NO. 30

The effort under Research Order No. 30 was conducted from March 8, 1956, through January 31, 1957, and the detailed results are described in the "Summary Report on Research Order No. 30", dated January 31, 1957. The prime objective of this program, as originally proposed, was to evaluate 5/16-inch-diameter diamond drills. The second objective was to prepare 10 experimental drilling kits for field testing by the Sponsor; each was to include: (1) a 50-cycle, 110/220-volt motor, (2) a flexible shaft, (3) a drilling head, (4) collectors for dust and water, (5) sets of diamond, and possibly carbide, drills for drilling holes up to 30 inches in depth, (6) an axial loading device, (7) water- and air-supply systems, and (8) a cheap carrying case. The third objective was to prepare drawings and specifications of the experimental drilling kit and the drills, and an operator's manual covering the use of the drilling kit.

As a result of discussions with the Sponsor, the original objectives were modified, by Supplement No. 1 dated September 28, 1956. The second and third objectives of the program were replaced with two others. One of the new objectives was to conduct an investigation directed toward developing a prototype drilling unit equipped with a lightweight, relatively quiet, electric motor integral with the drilling head, to replace the separate electric motor and flexible-shaft drive of the prototype drilling unit developed under Research Order No. 21; and also to design and develop suitable collecting devices for dust and water. The second new objective was to conduct a study of drilling with 1/8-inch-diameter diamond drills in granite, plaster, concrete, brick, marble, and other mutually agreed upon materials.

In order to evaluate 5/16-inch-diameter diamond drills, drill manufacturing companies were contacted and representative drills were purchased; suitable test equipment was designed and constructed; and the drills were tested under predetermined conditions. Twenty-eight drill manufacturers were contacted and 10 types of drills were received from 9 companies. It was hoped that the test equipment which had been developed under Research Order No. 21 would be satisfactory for the evaluation of the 5/16-inch-diameter drills. However, even after some modification of the original equipment, it was necessary to design and construct a special assembly to hold the material being drilled. With this assembly, it was possible to measure the torque which was imparted to the material from the drills by means of an arm incorporating a strain gage.

Tests were made to determine the drilling rate of the test drills in marble at 1/10 and 1/5 horsepower for speeds of 1,000, 2,000, 3,000, and 4,000 RPM. Because of difficulties from plugging, overheating, or inadequate cooling and/or flushing, the drilling tests with five of the 10 drills could not be completed. In tests with the five remaining drills, the fastest drilling rates were obtained with two core drills, and the third highest drilling rate was obtained with a non-coring drill. It was recommended that all three of these drills be field tested by the Sponsor, so as to ascertain which are the best drills from the standpoint of the Sponsor's applications. It was expected that the non-coring drill would be the easiest to use, but that the core drills would provide a higher drilling rate.

The drilling rates for these three 5/16-inch-diameter diamond drills were determined in plaster, brick, blue stone, marble, concrete, and granite with a 1/10-horsepower input. The rates obtained varied from 1/2 inch per minute in granite and 2 inches per minute in concrete, to 50 inches per minute in plaster.

The primary problem connected with the design of a lightweight drilling unit was the selection of an electric motor which would fit into a hand drill, provide sufficient power, and be relatively quiet. Electric-motor manufacturing companies were contacted to determine the feasibility of redesigning high-speed motors presently used in hand tools, in order to obtain quieter operation. It was the opinion of these companies that the noise of these units could not be materially reduced. A discussion of the problem was held with Robbins and Myers, Springfield, Ohio, and a 1/8-horsepower, 2,500-RPM, shunt-wound DC motor was selected as a unit that would provide the best combination of power, low weight, and little noise.

Tests with this motor in our laboratory were satisfactory and a lightweight drilling unit incorporating this motor was designed. This unit consisted of a drilling head and a power supply. The drilling head included the electric motor, a lightweight housing, and a water swivel for supplying water to the diamond drills. The power supply included the necessary electrical cords and a rectifying unit to supply the motor with direct current. The appearance of the lightweight drilling unit, Figure 3, was very similar to that of commercial 1/3-horsepower hand drills.

Several devices were designed and tested before a suitable unit was found for collecting both dust and water. The satisfactory unit used two rubber seals in contact with the drill shank to restrict the flushing

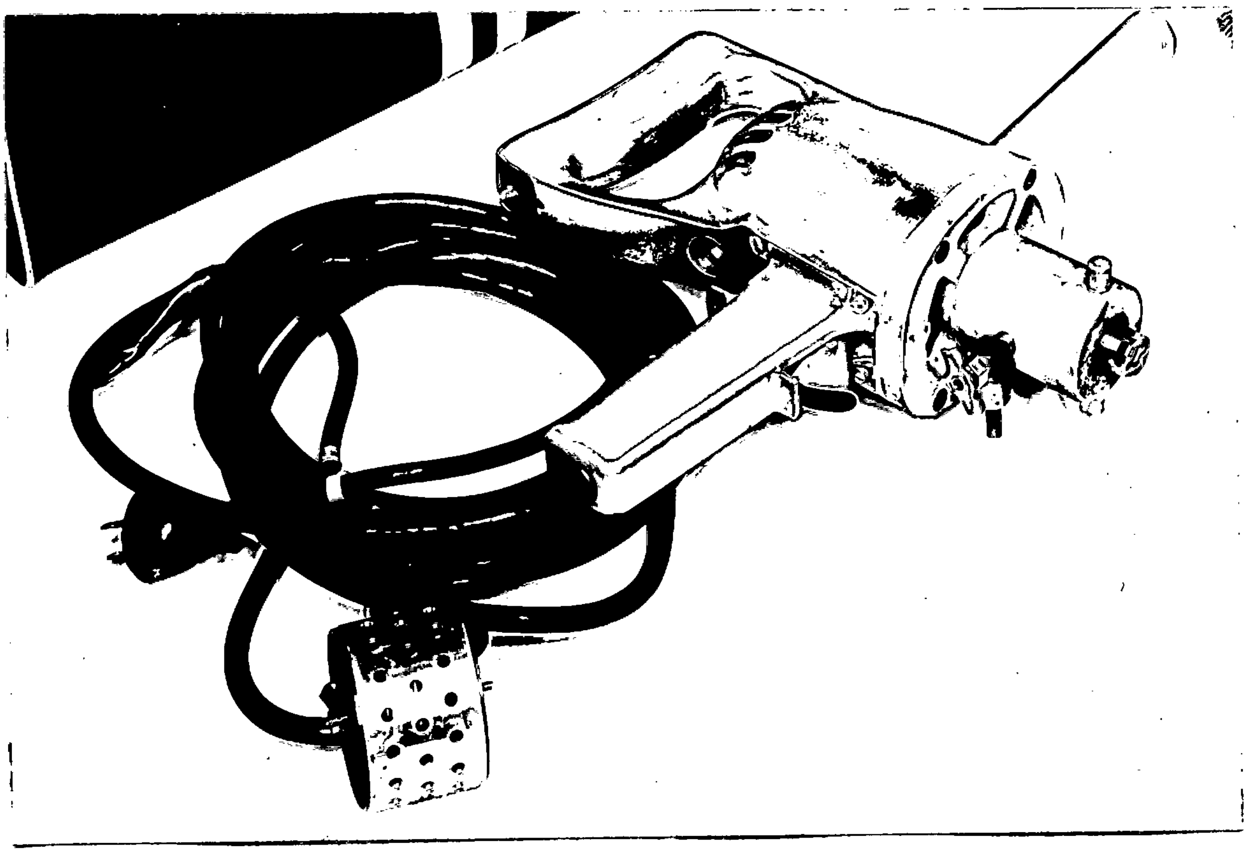

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Figure 3. The Original Lightweight Drilling Unit With Integral Electric Motor

medium. A chamber between these seals contained grease, which lubricated the drill shank. As the grease was used up, the grease chamber was reduced in size by turning a threaded plug. The collector was designed to be held against the wall by a plastic anchor such as the one developed under Research Order No. 21.

A drilling kit, as shown in Figure 4, was assembled from the units developed under Research Order No. 30 and those which had been developed under Research Order No. 21. The components of this kit, called the Type 2 Prototype Drilling Kit, consisted of a carrying bag, 20 feet of electrical connecting wire, a rectifier, a drilling unit, a water tank, a CO_2 cylinder, a dust-and-water collector, the necessary tubing, and three 5/16-inch-diameter diamond drills. The entire kit weighed 15 pounds and had the appearance of an overnight bag.

Subsequent to the development of the lightweight drilling kit, consideration was given to the procurement of 1/8-inch-diameter diamond drills for evaluation. The nine manufacturers who had been contacted previously all said that it was not practical to drill holes deeper than a few inches with 1/8-inch-diameter diamond drills. Consequently, 3/16-inch-diameter diamond drills were purchased from one of the drill manufacturing companies, and fitted with 1/8-inch-diameter shanks; drilling tests were then made in brick, bluestone, concrete, marble, and granite. At first it appeared that three 3/16-inch-diameter drills would be necessary in order to drill a hole 30 inches deep; during drilling, each drill would have a maximum unsupported shaft length of 10 inches. However, it was possible to drill with an unsupported shaft length of 15 inches if the operator was careful during the first 3 or 4 inches of drilling. Cursory tests with

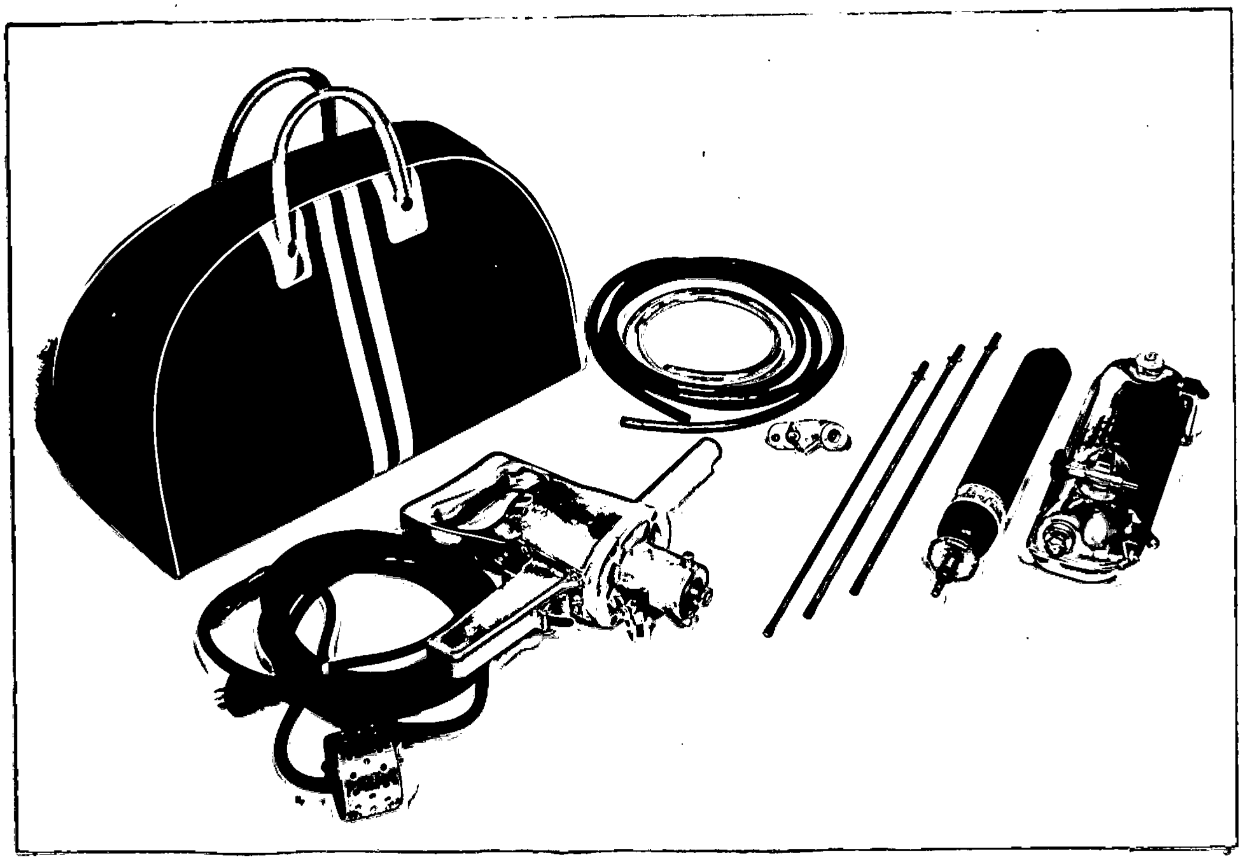

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Figure 4. The Type 2 Prototype Drilling Kit

the 3/16-inch-diameter diamond drills were so successful that it was felt that the 5/16-inch-diameter diamond drills could be replaced by the smaller drills for many of the Sponsor's applications.

APPENDIX 3

WORK ORDER NO. XI, TASK ORDER NO. A

The effort under Work Order No. XI, Task Order No. A, was conducted from March 1 through July 31, 1957, and the detailed results are presented in the "Summary Report on Work Order No. XI, Task Order No. A", dated July 31, 1957. The work was undertaken to (1) prepare an experimental drilling kit similar to that developed under Research Order No. 30, and (2) to evaluate further the performance of 3/16-inch-diameter, diamond-tip drills.

The drilling kit prepared under this program, Figure 5, was basically the same as the one developed under Research Order No. 30. The water swivel was changed from the front of the drill housing to the back to simplify the construction, and the rectifier unit was fused to protect the rectifiers. The water tank, CO_2 cylinder, and carrying case were the same as before, but as agreed upon with the Sponsor, no drills were furnished.

The water and dust collector supplied with the kit was developed under Task Order No. O.

Subsequent to the preparation of the drilling kit, 3/16-inch-diameter diamond drills were purchased and fitted with 5/32-inch-diameter shafts; and drilling tests then made in plaster, brick, blue stone, marble, concrete, and granite. The drilling unit with a maximum capacity of 1/8 horsepower was used to power the drills for the tests. Laboratory equipment was set up to measure the drill power input and also to determine drill

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Figure 5. The Modified Drilling Kit

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penetration rates. The results of these tests, listed in Table 4, indicated that the 3/16-inch-diameter diamond drills could be used satisfactorily to drill through 30 inches of masonry-type building materials.

Table 4. Drilling Rates of 3/16- And 5/16-Inch-Diameter Diamond Drills

Material	Drill Type	Drilling Rate, inches/minute	Horsepower Input to Drill
Plaster*	3/16-inch noncoring	40	0.01
	3/16-inch coring	20	0.002
	5/16-inch noncoring(1)	27-1/2	0.1
	5/16-inch coring(2)	31	0.1
Brick	3/16-inch noncoring	15	0.02
	3/16-inch coring	17-1/4	0.06
	5/16-inch noncoring(1)	8-1/2	0.1
	5/16-inch coring(2)	14-1/2	0.1
Blue Stone	3/16-inch noncoring	6-1/8	0.05
	3/16-inch coring	10-3/4	0.07
	5/16-inch noncoring(1)	3-1/2	0.1
	5/16-inch coring(2)	5	0.1
Marble	3/16-inch noncoring	4-1/8	0.06
	3/16-inch coring	3-5/8	0.1
	5/16-inch noncoring(1)	1-1/2	0.1
	5/16-inch coring(2)	3-1/4	0.1
Concrete	3/16-inch noncoring	8-1/8	0.07
	3/16-inch coring	6-3/4	0.08
	5/16-inch noncoring(1)	2-1/4	0.1
	5/16-inch coring(2)	2-1/4	0.1
Granite	3/16-inch noncoring	4-1/8	0.06
	3/16-inch coring	3-1/4	0.07
	5/16-inch noncoring(1)	1/2	0.1
	5/16-inch coring(2)	1/2	0.1

Footnotes on following page.

Footnotes for Table 4

*To complete the basis for comparison between the performances of 3/16 and of 5/16-inch-diameter diamond drills, drilling tests were conducted in plaster also.

(1) Obtained using surface-set noncoring drill, purchased from the Wheel Truing Tool Company, 3200 W. Davison Avenue, Detroit 6, Michigan.

(2) Obtained using surface-set core drill, purchased from the Hoffman Brothers Drilling Company, Punxsutawney, Pennsylvania.

Note: For description and discussion of diamond drills and drilling rates, see "Summary Report on Research Order No. 30", dated January 31, 1957.

APPENDIX 4

TASK ORDER NO. H

The work under Task Order No. H was conducted from December 3, 1956, through August 31, 1957, and the detailed results are described in the "Summary Report on Task Order No. H", dated August 31, 1957. The objective of this program was the development of an auxiliary tensioning device which could be used to apply an axial load on a drill without taxing the strength and endurance of the operator. Also three prototype units, and drawings, specifications, and an operator's manual were to be prepared.

Of the more than 30 ideas which were evolved and evaluated, an idea involving a windlass or winch-like design was selected for development. The windlass unit developed consisted essentially of two drums on a common shaft that wound up two cords, one on either side of the drill. The cords were connected to tension springs, to store the energy needed to produce thrust on the drill. To provide the necessary leverage, reduction gears and a 6-inch-long lever arm were used. For ease of operation, the lever arm was operated through a ratchet and clutch. The ratchet was set up to release the arm on the return stroke and the clutch permitted rapid unwinding of the cords. The first experimental tensioning device is shown in Figure 6.

Evaluation of this unit showed the need for two modifications: (1) to permit angle drilling in the range of 90 to 45 degrees from the surface being drilled, and (2) to provide for mounting the device either on the surface to be drilled or on the frame of the drilling unit. These requirements were met by designing the mechanism in two parts - a removable

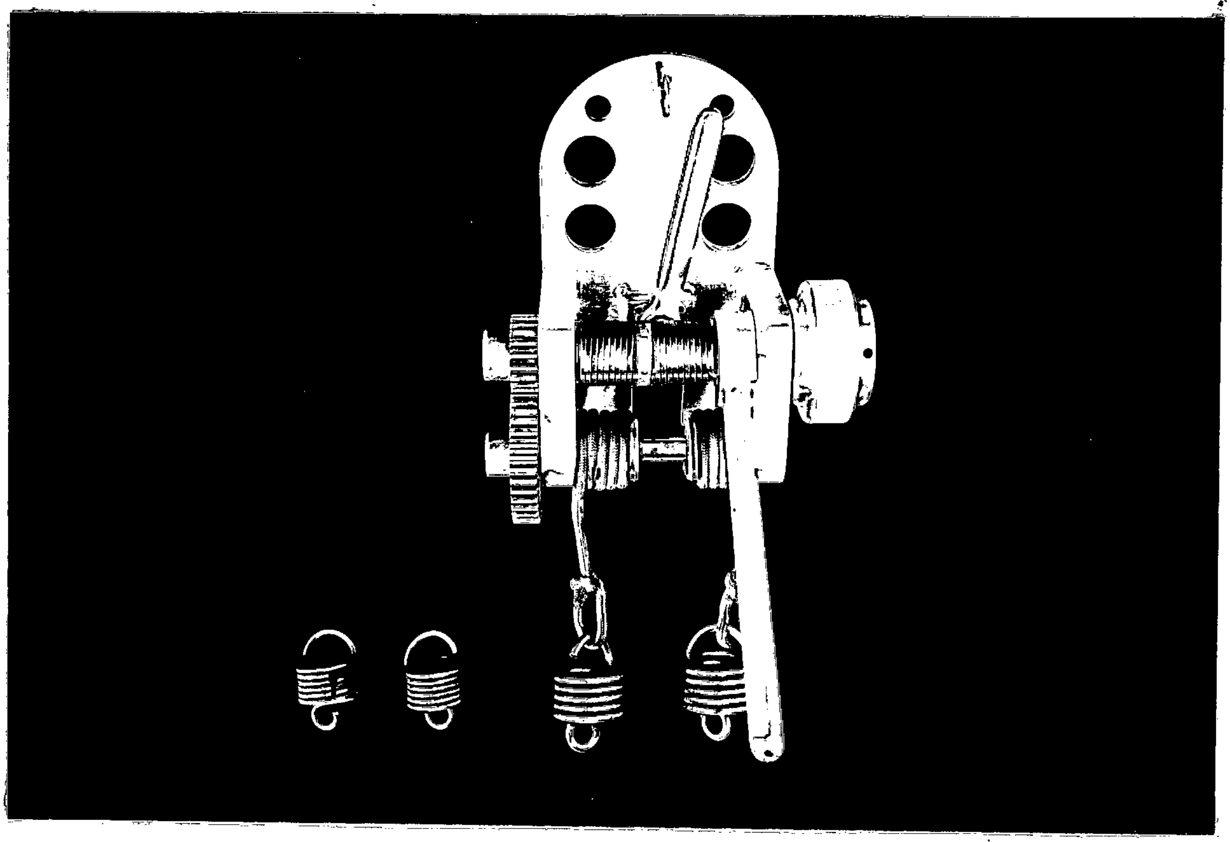

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Figure 6. The First Experimental Tensioning Device

base plate and a self-contained winch. This unit is shown in Figure 7. For operation on the surface to be drilled, the winch was fastened to the base plate in a position to give the desired drilling angle, and the entire assembly was mounted using the anchor stud. For operation on the drilling unit, the winch only was mounted on the drilling unit and the base plate was fastened, by means of the anchor studs, to the surface to be drilled. When the Sponsor requested a water and dust collector for use in drilling perpendicular to the wall, we contemplated adapting the collector developed under Research Order No. 21. This did not prove to be feasible, and several new collector designs had to be evolved, and operating units prepared and evaluated. Subsequently, a satisfactory water and dust collector was prepared entirely of rubber.

Three prototype tensioning-device units were fabricated and production drawings, specifications, and an operator's manual were prepared.

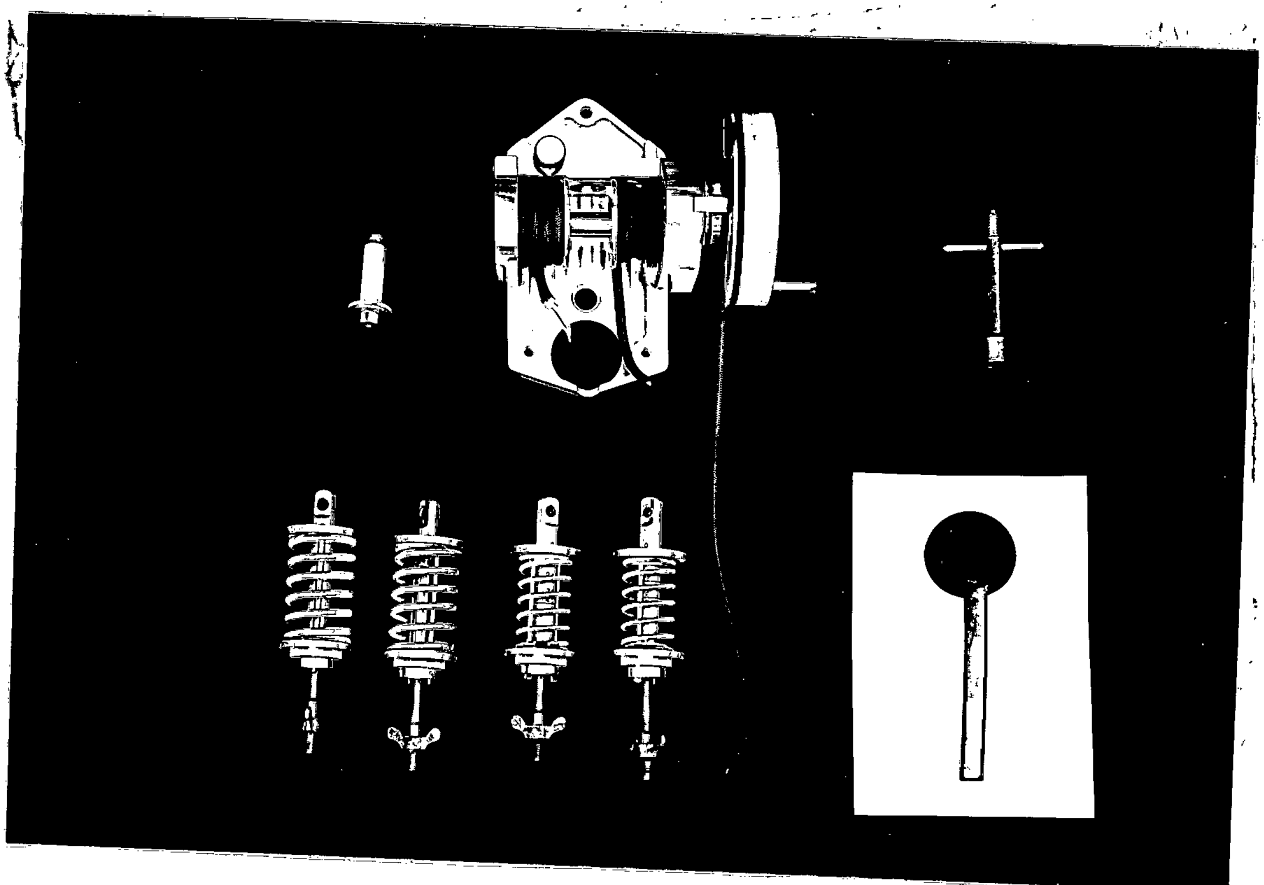

Figure 7. The Prototype Tensioning Device

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APPENDIX 5

TASK ORDER NO. O

The work under Task Order No. O was conducted from May 31 through November 30, 1957. The detailed results were presented in the "Summary Report on Task Order No. O", dated November 30, 1957.

Task Order No. O was undertaken to prepare 10 modified drilling kits and to prepare specifications, drawings, and an operator's manual for the kits. During the course of the effort, Task Order No. O was modified by agreement with the Sponsor to include two additional drilling kits and four additional armature and field units instead of drills for each kit as originally specified; of the 12 kits and four armature-field units to be supplied, six kits and two armature-field units were to operate on 115 volts, and the remaining units on 230 volts. In addition, it was agreed that no carrying cases would be supplied with the 12 kits.

The drilling kits, Figure 8, which were fabricated under Task Order No. O were based on the work done previously under Research Order No. 30 and Work Order No. XI, Task Order No. A. Improvements in the hand-held drilling units included changing the position of the water swivel from the front to the back of the drilling-unit housing so as to simplify construction, and placing the rectifier unit within the drilling-unit housing. A disassembled drilling unit is shown in Figure 9. The water and dust collector developed under Task Order No. H was modified slightly for the 12 kits. The water tanks and CO_2 cylinders were almost the same as those used for Research Order No. 30. Each of the kits was tested prior to shipment to the Sponsor, and no major difficulties were encountered.

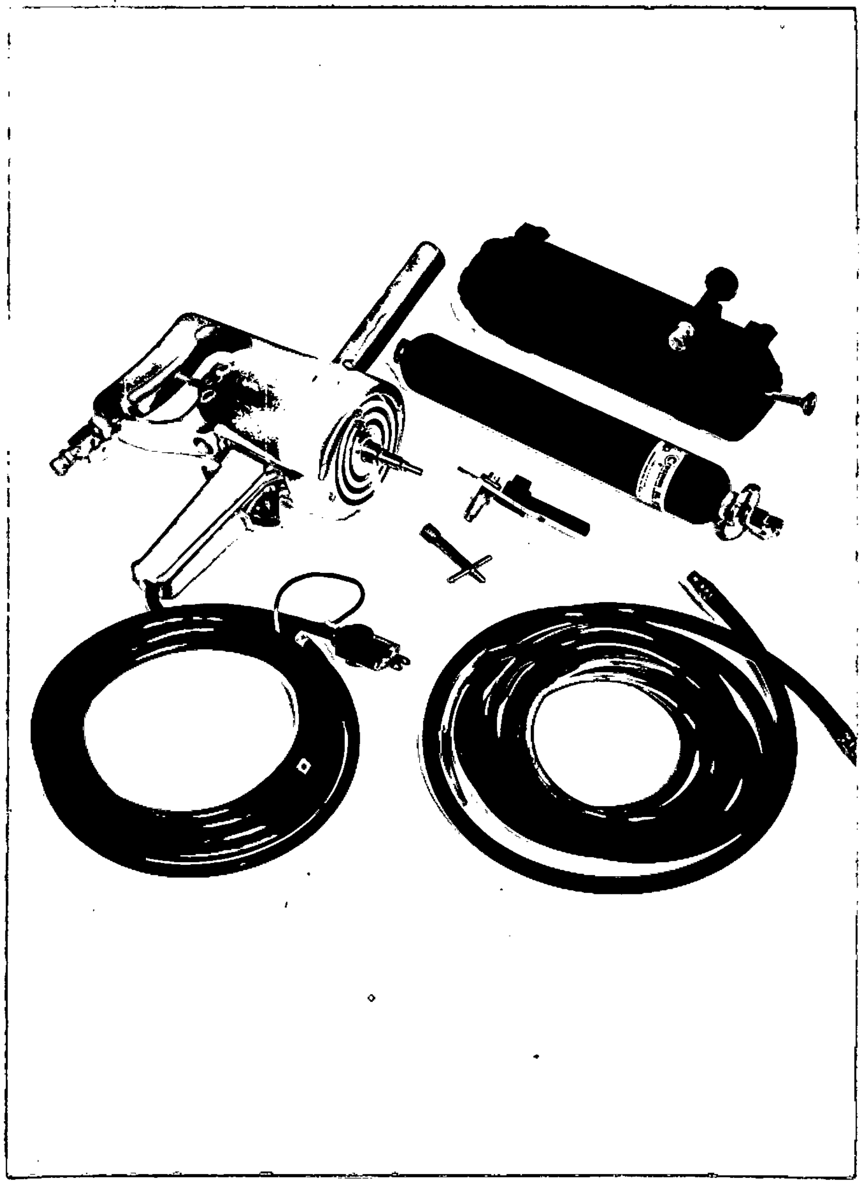

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Figure 8. The Further Modified Drilling Kit

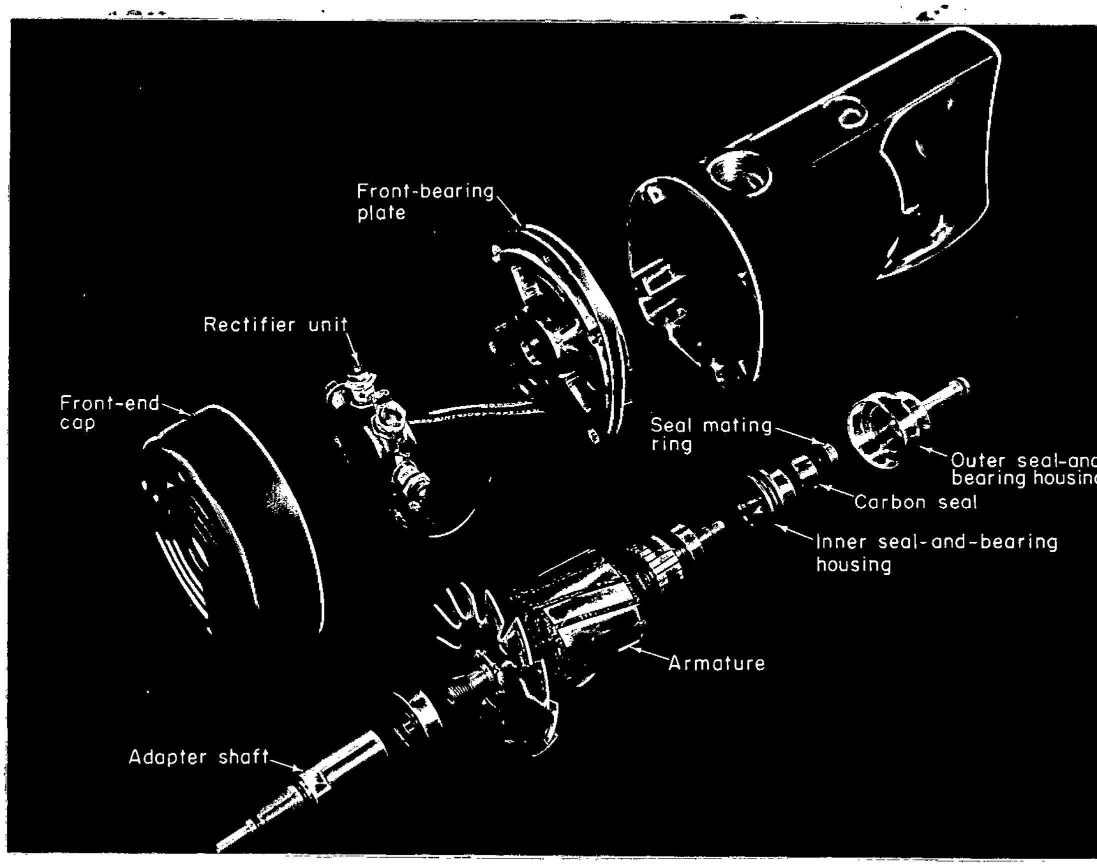

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Figure 9. Disassembly of the Drilling Unit

An operator's manual which described in detail the use and maintenance of a drilling kit was prepared and submitted on October 4, 1957. Subsequently production drawings and manufacturing specifications for the kit were prepared and submitted.

Toward the end of the program, cursory experiments showed that if the output of the motor was changed from 1/8 horsepower at 2,500 RPM to 1/10 horsepower at 1,800 RPM, the noise of the unit would be reduced considerably and the increase in motor temperature [rise] would not be excessive. Consequently, it was recommended that the lower output motor be seriously considered for use in any future drilling kits.

APPENDIX 6

WORK ORDER NO. II, TASK ORDER NO. R

The effort under Work Order No. II, Task Order No. R, was conducted from November 7, 1957 through March 6, 1958. The results are described in a summary letter report dated May 13, 1958.

One of the drilling requirements that became apparent during the activity under Task Order No. H was that it should be possible for the operator to be able to drill at angles up to 45 degrees from a perpendicular to the working surface. The experimental water and dust collector which had been developed under Research Order No. 30 was not able to accommodate angular drilling. Further, no provision had been made under Task Order No. H for consideration of such a water and dust collector, although the collector developed under Task Order No. H was able to accommodate drilling at small angles. Consequently, Work Order No. II was undertaken to develop an experimental water and dust collector for use with the experimental drilling unit and the experimental tensioning device during angular drilling.

Three modified designs of the water and dust collector developed under Task Order No. H were fabricated and evaluated. These are shown in Figure 10. Each of these units consisted of an assembly of two parts, namely, the housing and the drain tube. The water and dust collector housing comprised the face seal, a bellows-type body section, and a shaft seal. The drain tube was a piece of natural-rubber tubing cemented into the body section. The tests on these collectors were conducted at an angle of 45 degrees using a 7/16-inch-diameter carbide-tipped drill with a 3/8-inch-diameter shank.

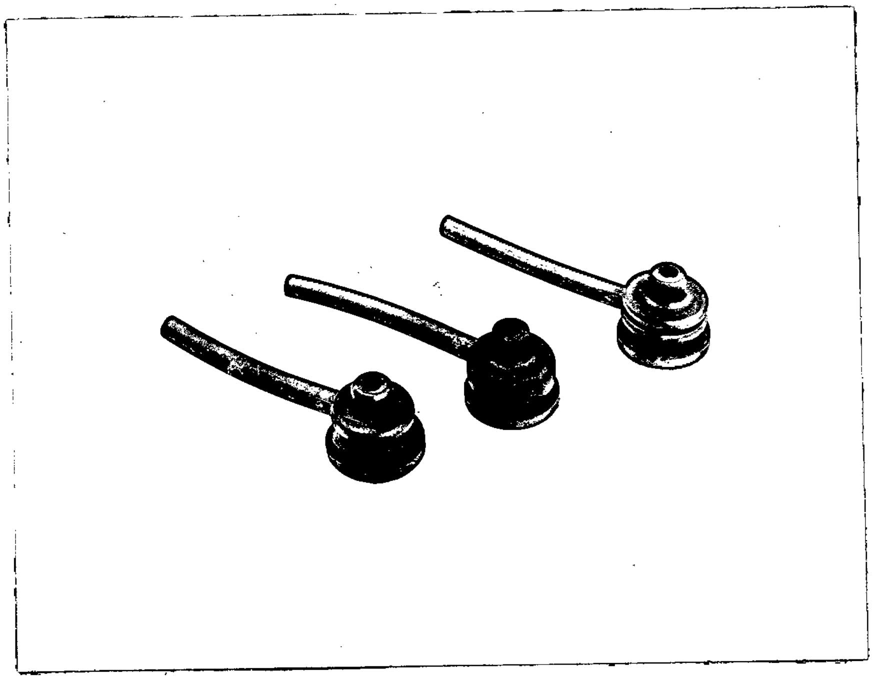

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Figure 10. Three Designs of Water and Dust Collectors

The test results showed that these units were not satisfactory. However, because a new base-plate or wall-plate design was being considered, it was decided that any improvements on a water and dust collector for angular drilling would be incorporated in the new base plates.

APPENDIX 7

TASK ORDER NO. BB

The work under Task Order No. BB was conducted from May 1 through November 30, 1958, and was described in the "Summary Report on Task Order No. BB", dated November 30, 1958. The objective of this effort was to design and develop a specialized attachment for the Task Order No. O drilling unit and to prepare three prototype units of the attachment; the attachment was to make possible the drilling of holes in corners or in locations close to an abutting wall.

Preliminary experiments indicated that a rubber hose or flexible cable might be used to transmit the motor torque. An investigation was made to obtain some indication of the torque levels involved at various drilling speeds. An experimental attachment was subsequently prepared for use with the Task Order No. O drilling unit, and holes were then drilled with this device in various masonry-type materials.

The first experimental model utilized a rubber hose with an internal spring that transmitted both the torque and the thrust loads. This model proved to be unsatisfactory. A second model was then fabricated in which the rubber hose with an internal spring was used to transmit the torque only. The thrust loads in this unit were absorbed by a bearing block assembled to a sheet-metal frame which was attached to the drilling-unit housing. This model included antifriction bearings; these were necessarily very small, and were ultimately considered to be unsatisfactory because they were too highly loaded to provide reasonable life under anticipated service conditions.

A third experimental model was prepared with plain bearings rather than antifriction bearings. This model appeared to be satisfactory; however, extended evaluation suggested that the rubber-hose drive member with an internal spring would probably not provide a long enough life at the operating torque loads. Therefore, a fourth experimental model was fabricated.

In the fourth model a flexible cable transmitted the torque; the cable was enclosed in a rubber sheath and the flushing fluid was passed along the annulus between the flexible cable and the rubber sheath. Life tests showed that this flexible cable would probably provide a long enough life if in its application it was bent through only about 30 degrees rather than 40 degrees. Three prototype units, Figure 11, based on the fourth model and three spare flexible drive assemblies were fabricated and submitted to the Sponsor.

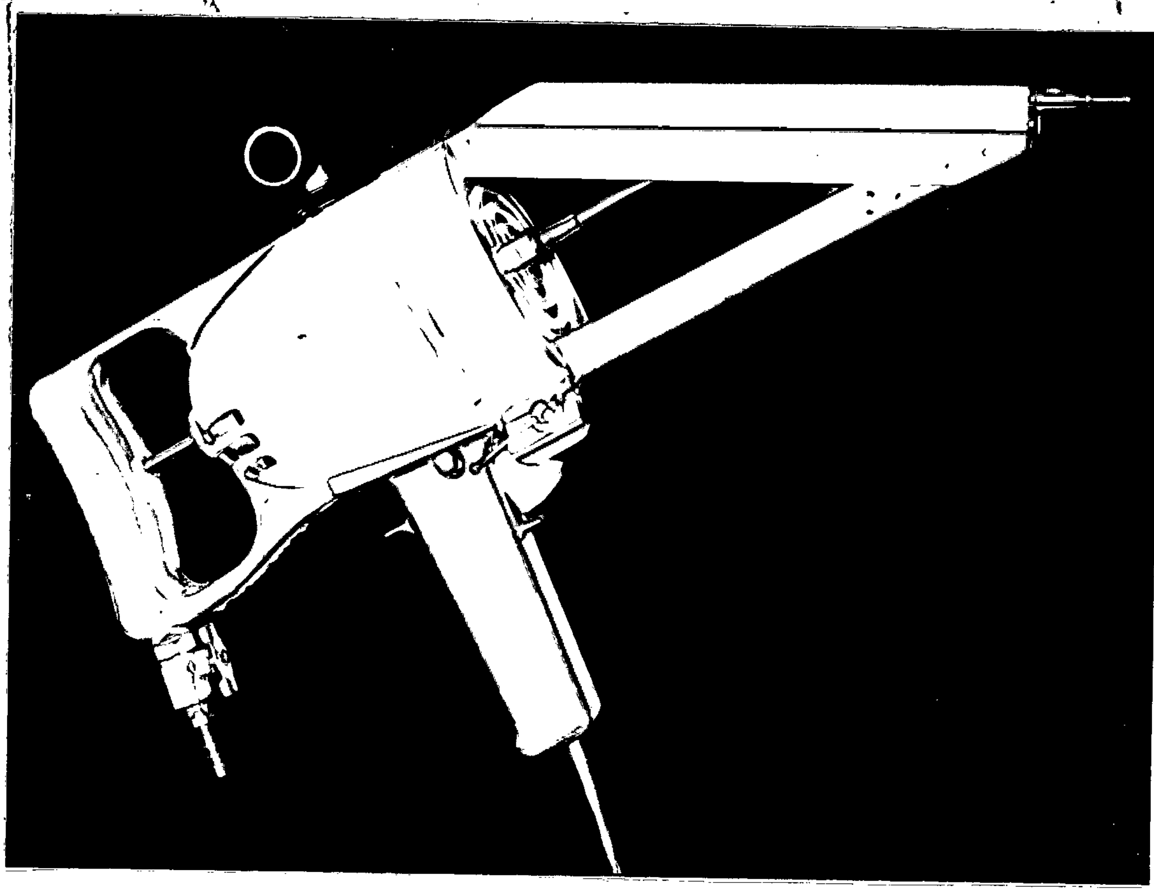

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Figure 11. Prototype Corner-Drilling Attachment

APPENDIX 8

TASK ORDER NO. W

The effort under Task Order No. W was conducted from March 24 through July 23, 1958, and the results were described in the "Summary Report on Task Order No. W", dated July 23, 1958. Task Order No. W was undertaken to develop a specialized wall-plate assembly, hereafter called a wall drill swivel. This assembly was to be designed so that it could be used interchangeably both with the winch portion of the tensioning device, developed under Task Order No. H, when the winch was mounted on a hand-operated drilling unit, and with the electric drilling unit, developed under Task Order No. O. Originally, the proposed wall drill swivel was to provide for angular drilling at 0 to 60 degrees from the perpendicular to the work surface; for the collection of water and/or dust from drilling operations conducted with 3/8- and 1-inch-diameter diamond core drills; and for an adjustable drill-depth stop to permit control of the depth of the hole being drilled. One experimental wall drill swivel and appropriate working drawings were to be prepared. During the course of the project, the angular requirements were changed from 0 to 60 degrees to 0 to 45 degrees.

As a result of preliminary design efforts, certain principles of operation were selected for test, to establish the general configuration of the major components. The following components were fabricated for these tests: a 60-degree-angle drill guide, a simulated base-plate and yoke-type clamp, a tensioning-device spring system, and a rubber-sleeve-type-collet drill-depth stop. Based on the results of these tests, a wall-drill-swivel design was prepared and a wooden mock-up of the device was constructed. Subsequently, the device was fabricated and detailed shop drawings were prepared.

In our tests, the wall drill swivel was used to drill holes at various angles, up to 45 degrees from the perpendicular to the working surface, in concrete and granite with 3/8- and 1-inch-diameter diamond drills. A hand-operated drilling device, and also an electric drilling unit which was developed under Task Order No. O, were used individually to supply power to the drills. The winch assembly of the tensioning device which had been developed under Task Order No. H was also used in conjunction with the spring assembly of the wall drill swivel to apply a load to the drills. As a result of such tests performed in our laboratories and also by the Sponsor, the 3/8-inch drill-guide insert, the drill-shank seals, and the water-collector components of the wall drill swivel were modified; the unit was tested and performed satisfactorily. The modified wall drill swivel is shown in Figure 12.

Working drawings of the modified wall drill swivel were subsequently prepared and submitted to the Sponsor.

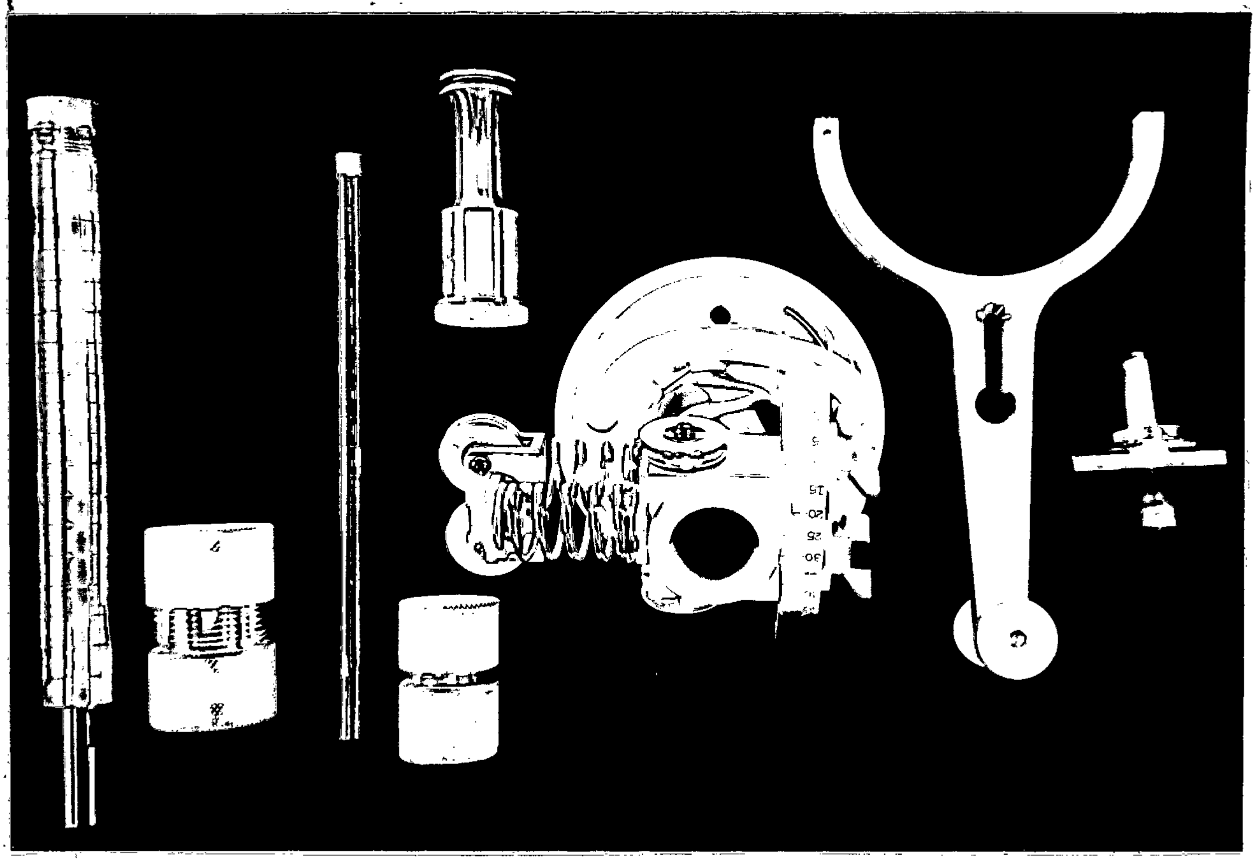

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Figure 12. The Modified Well Drill Swivel and 3/8- and 1-Inch-Diameter Diamond Core Drills

APPENDIX 9

WORK ORDER NO. II, TASK ORDER NO. CC

The effort under this program was performed from November 18, 1958 through February 17, 1959. A summary letter report dated April 29, 1959, describes the results obtained. Work Order No. II was undertaken to modify the following parts of the experimental wall drill swivel which was developed under Task Order No. W: (1) stop collar, (2) adapter, (3) yoke, (4) yoke insert, (5) bearing block, (6) spring mounting, and (7) base. The modifications were made and the working drawings changed accordingly. A modified wall drill swivel was submitted to the Sponsor for evaluation.

APPENDIX 10

TASK ORDER NO. VV

The effort under Task Order No. VV was conducted from November 14, 1960, through April 14, 1961, and described in the "Summary Letter Report on Task Order No. VV", dated April 14, 1961. The objective of this program was to develop a corner-drilling attachment which could be mounted on the modified version of the drilling unit evolved previously under Task Order No. O, and which would permit the use of both 3/8- and 1-inch-diameter drills on the basis of the new drill-attachment arrangement.

A corner-drilling attachment, shown in Figure 13, was designed, developed, and tested; its performance was satisfactory. The experimental attachment, together with an alternate sheet-metal housing, was submitted to the Sponsor for further evaluation.

Because the attachment of interest was to accommodate 1- as well as 3/8-inch-diameter drills, it was possible to use, as a part of the attachment, a hose of larger diameter than that developed under Task Order No. BB. Two types of standard hydraulic hose were tested with bend angles up to 35 degrees and found to be satisfactory after 100 hours of operation. This change made possible an attachment unit with a much longer life than that of the unit developed under Task Order No. BB.

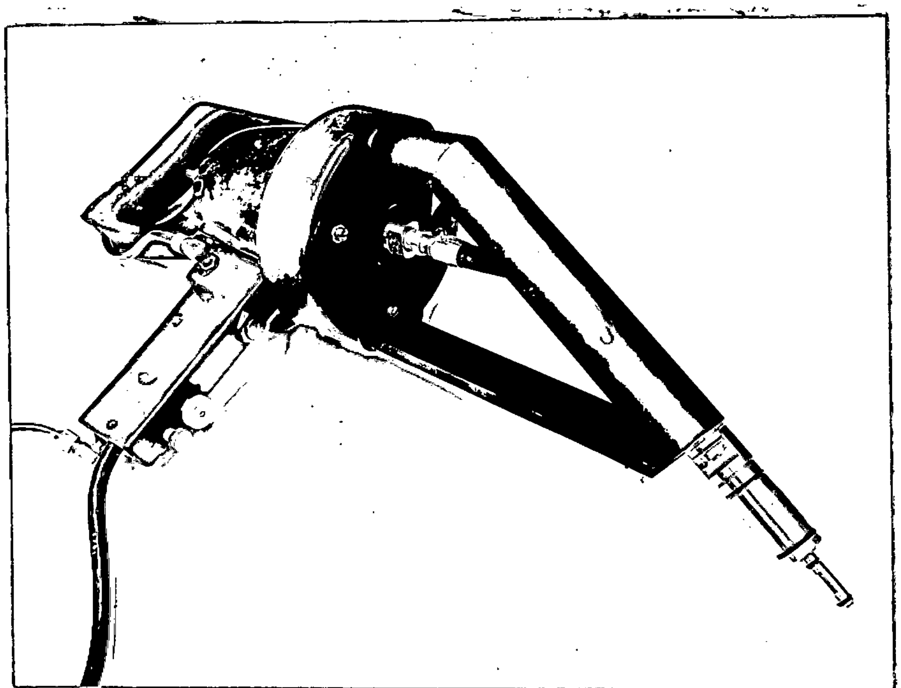

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Figure 13. The Experimental Corner-Drilling Attachment, In Position on the Drilling Unit

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APPENDIX 11

WORK ORDER NO. IV, TASK ORDER NO. CC

The effort under this program was conducted from November 18, 1958, through February 17, 1959; the detailed results are presented in a summary letter report dated May 1, 1959. Under this program, an experimental pumping device was evolved that was capable of delivering 120 cc of water per minute at a pressure of from 10 to 30 psi, and also of supplying 96 cc per minute when pumping against a pressure of over 200 psi. However, the further development of this design was discontinued in favor of investigation of a pump based on a mechanism used in a commercial paint sprayer (Task Order No. II).

APPENDIX 12

TASK ORDER NO. II

The work under Task Order No. II was conducted from April 23 through August 22, 1959, and described in the "Summary Report on Task Order No. II", dated August 22, 1959. The objective of this program was the development of a simple mechanism for pumping water for the 115- and 230-volt drilling units. The Sponsor had obtained a commercially available paint-spraying device which appeared to have a very simple mechanism for pumping water. Preliminary study of this unit in our laboratories showed that the pumping mechanism would probably be adequate for the application of interest.

After considerable laboratory evaluation and modification, a pump mechanism was developed that showed adequate life for the proposed application. Possible motors and driving mechanisms for operating the pump were evaluated. In view of the light weight required of this device, it was decided that the motor would have to be water cooled in order to keep the size to a minimum. This principle was similar to that used for the motor in the drilling unit. A water-cooled motor was fabricated and operated successfully. At this point the noise of the pumping mechanism and drive unit became a problem. A satisfactory noise level was attained by placing the water-cooled unit in a sound-proofing enclosure. Although the resulting equipment, shown in Figure 14, operated satisfactorily, its advantages over the hand-pressurized water tank were not sufficient to warrant its incorporation in the drilling kit.

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Figure 14. The Experimental Specialized Pump Assembly Including Speed Control and Enclosure

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