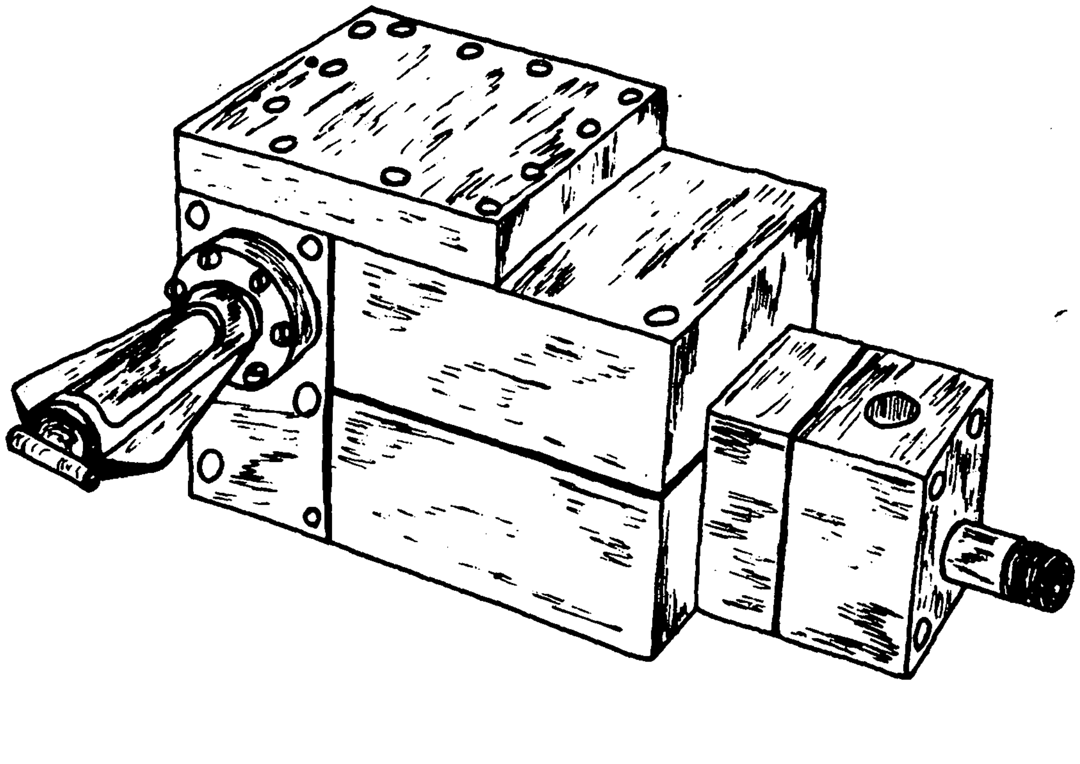
# FINAL REPORT
# on the
# DEVELOPMENT OF THE
# ROBOMETER



AN APPROPRIATE TECHNOLOGY DEVICE

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# FINAL REPORT

on the

# DEVELOPMENT OF THE ROBOMETER

Prepared for

The U.S. Agency for International Development

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January 1979

## TABLE OF CONTENTS

TABLE OF CONTENTS

FIGURES (Continued)



APPENDIX

## SUMMARY

The objective of this project was to develop a nonproprietary, individual house, user activated water meter which is inexpensive, low in operating and maintenance cost, and can be produced in most LDC's. The activating mechanism of the meter is a small cylinder or cartridge filled with compressed air. The cartridges are light in weight and the technology and equipment for manufacturing and recharging them is available. Marketing of these cartridges in LDC's is not considered a problem. The consumer will be able to purchase the cartridges at any approved outlet or store.

Activating the meter is done by inserting the cartridge into the breech of the meter. As the compressed gas is released, it pushes a piston which opens a valve, allowing the water to flow through the meter. The cartridge is used on a one-shot basis and can be returned to the central facility for recharging. In effect, the water paid for is now in storage to be used at the consumer's discretion. The meter can be set to deliver a predetermined amount of water per activation.

With a user activated water meter, the consumer, in essence, buys the water prior to using it. Billing costs, collection of payments, poor debts, etc., are therefore eliminated, and the utility company receives payment for operating and maintenance.

The user activated meter allows the consumer to buy water in small lots ($1m^3$ to $4m^3$) that he can afford, and has the cash on hand to pay for water delivered to his/her household. Thus, the consumer's burden of paying what may be a large sum on an infrequent billing interval is avoided.

The user activated water meter is a key element in a new marketing approach to provide utilities with the necessary revenues. Guaranteeing payment for water delivered with minimum of collection costs will encourage utilities to expand service to consumers in poor sections of the community that are deprived of safe clean water. At the present time, many utilities refuse to expand service to such sections because of the difficulties encountered in payment collection for water delivery.

The purpose and goals of this project have been successfully met. A working model of the meter has been constructed and subjected to limited testing. The results of this project demonstrate that a user activated water meter is feasible. Further development, however, including laboratory and field testing, is necessary before it can be manufactured and utilized in LDC's.

The interest of the international community in this meter is appreciated. Many representatives of different organizations have foreseen broad applications of the proposed water metering and marketing approach for LDC's, as well as developed countries.

INTRODUCTION

Water utilities in the developing world are unique in the sense that they normally face high operating and maintenance costs, coupled with inadequate tariff rates and unreliable collection of revenues. Because of the difficulties and uncertainties encountered in receiving payments for water delivered, many water utilities are reluctant to expand services to the poor communities or districts where revenue collection is most difficult. Thus, consumers residing in poor districts often do not have access to high quality water at reasonable rates. If a water utility company can be provided with an inexpensive, efficient collection system for all of its customers, such a company may look favorably upon expanding its service. The approach to the solution of unreliable collection is a new marketing system wherein the consumer pays for the water prior to using it. Such a system will eliminate billing and collection costs, and uncollectible accounts. The key item in this approach is a user activated water meter.

Most water meters in use today are cast metal (brass or bronze) which are heavy, expensive, complicated, easily clogged, and not readily adaptable to production in LDC's because of proprietary patents. Recently, some water meters have been constructed out of various plastic materials. These meters are relatively inexpensive, costing from $20 to $40, and fairly accurate, i.e., $\pm$ 1%. Although such meters are mechanically good, they pose a number of serious problems, such as clogging, frequent maintenance, meter reading, etc. In order to collect payment, an employee of the water authority agency must read the meter and submit the data to a billing office. The billing office prepares a statement of charges which is then given to the user. This procedure requires considerable labor and expense and, in many cases, does not ensure collection of payment. In many LDC's the user simply does not have the money to pay a monthly or semi-monthly water bill, although he can pay on a day to day basis. It is also not uncommon to hear about corrupt water meter readers who, by various methods, render the water agency unable to collect fees for water used. In summary, existing water meters are labor intensive, expensive, and a high maintenance item.

On the other hand, a user activated meter does not depend upon meter reading and billing in order to collect payment for water used. A user activated meter is defined as a unit which is activated by an external device which can be purchased by the user at approved outlets, such as general stores, cantinas, local grocery stores, churches, government buildings, etc. Once the user has activated the meter, he is entitled to a predetermined volume of water available at a time of his choice. For instance, if the meter is set to dispense $3m^3$ of water, the consumer buys the activating device, inserts it into the meter and can draw up to $3m^3$ of water through the meter in any volume amounts, or time intervals, by opening and closing the faucet at will. When a total of $3m^3$ has been used, the meter will cut off the supply and the consumer will have to insert another activating device to obtain additional water. A visual warning system will be incorporated into future design to alert the consumer when the meter cutoff point is approaching. The whole key to the user activated approach is allowing the LDC consumer to buy water in small lots which he can afford and has the cash in hand to pay for water delivered into his/her household. In essence, the user, by purchasing the activator, has prepaid for the water that he will use.

In this system, payment is received prior to water use, while with ordinary billing systems, charges are assessed for water used after the water is consumed. In addition to the elimination of meter reading, billing, and collection of payment, the user activated meter will also help reduce revenue losses because of corrupt water meter readers. Only on occasions when infrequent maintenance is required will the user come in contact with an employee of the water supply agency.

The objective of the research and development project was to develop a user activated water meter that is simple to operate, rugged, reliable, low in operation and maintenance, and suited for LDC local manufacture, including spare parts.

This objective has been largely achieved inasmuch as a prototype meter has been constructed and subjected to limited testing. Although the feasibility of producing such a meter has been demonstrated, it is recognized that further development, including laboratory and field testing, is necessary prior to usage in LDC's.

A number of representatives from various international agencies have expressed a keen interest in the meter and its wide application. U.S.A.I.D. encourages the international community to become involved in the further development of the meter.

## DESCRIPTION OF THE ROBOMETER

A user activated meter has an obvious appeal for the water utility company and the individual consumer. The company receives its operation and maintenance costs with a minimum of billing and collection expenses. The consumer obtains, at a reasonable rate, reliable safe water, and paying for it is within his means. The activating agent must be unique in order to prevent fraud by easy duplication, tampering with the meter, etc. Various external activating devices were investigated before selecting one which cannot be easily duplicated. The activating device of the Robometer is a small cylinder of compressed gas, typically ten milliliters, which has a pressure of approximately 860 psi at ambient temperature. The pressurized cylinder or cartridge, shown in Figure A-1 (Appendix A), can be easily manufactured by the water authority or industry within the country and available for purchase in stores throughout the region.

The technology and equipment for manufacturing these cartridges is available. Such cartridges are manufactured and sold in a number of countries for making soda water. The cartridges are used on a one-shot basis. They are small, light in weight, and transportation and marketing are not considered major problems. The selling price will be determined by the agency in charge of water supply and, as an incentive, the establishments (grocery store, general stores, small village supply stores, etc.) where such cartridges are offered for sale will be guaranteed a small profit. After using the cartridge, the consumer may dispose of it or return it to the store for recharging. The feasibility of utilizing reusable cartridges depends on numerous factors which vary from country to country.

The present wholesale cost of a cartridge filled with scrubbed $CO_2$ is approximately $0.10. The cost of such cartridges for use as activating agents for the meter will be appreciably less because compressed air will be used instead of $CO_2$. Information on the costs associated with setting up a cartridge charging facility is difficult to obtain. Manufacturers who produce such cartridges were reluctant to discuss details of their operation. The low wholesale cost of the cartridge and the limited market suggest that the cost of the equipment is moderate.

The details of the meter are shown in Figures 1-12. The prototype, shown in Figures 1 and 2, was constructed and fabricated in a building block fashion, the "blocks" being positively located by hardened steel dowels, and held firmly in place by various sizes of hollow head cap screws and flat head machine screws. It is recognized that this method of manufacture could prove to be very costly, and only a few will be produced in this fashion for testing and monitoring purposes. The ultimate

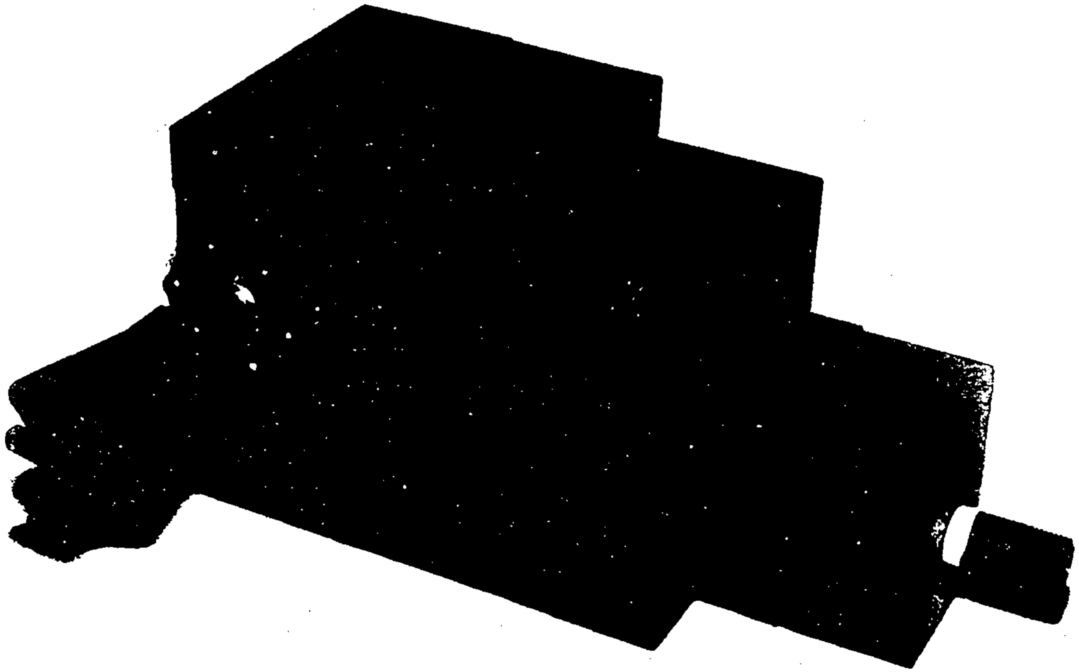


Figure 1: Robometer

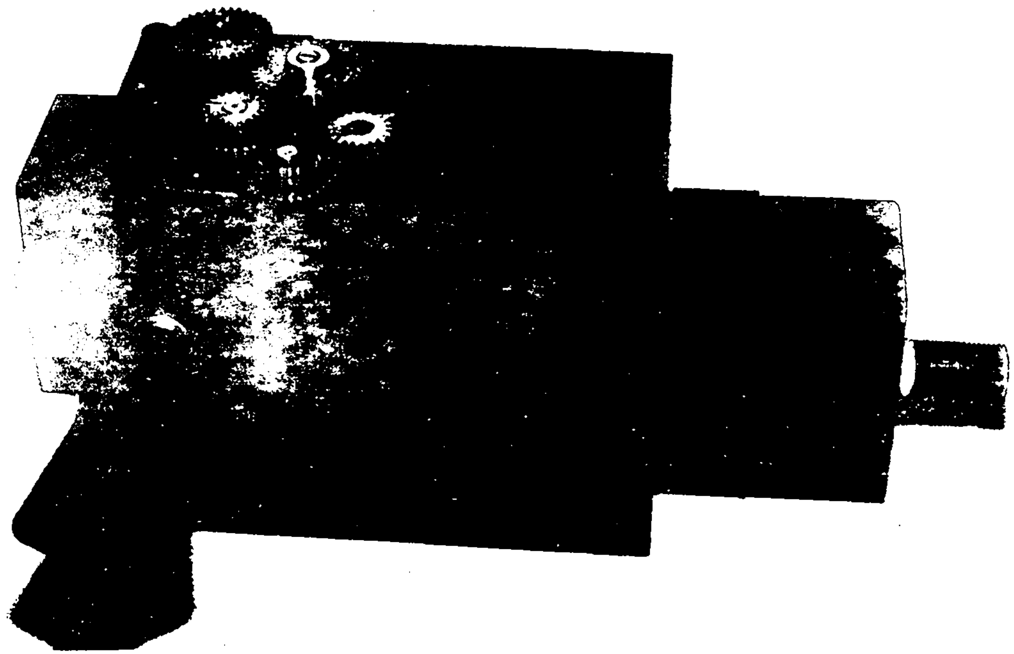


Figure 2: Robometer Showing Metering Gears and Breech Loaded with Cartridge

goal is to make the meters from thermoplastic materials, and injection mould the parts wherever possible.

To activate the meter, the consumer inserts the compressed gas cyclinder or cartridge into the breech of the meter shown in Figure 3. As the gas from the cylinder expands, it exerts pressure on the piston (Figure 4). The forward motion of the piston and shaft opens the valve as shown in Figure 5. With the valve now open, water can reach the user's faucet. The sole function of the pressurized cartridge is to push the piston in order to open the valve. A cartridge pressure of no less than 600 psi will activate the piston. Thus, bicycle pumps or commonly used compressors cannot be used in lieu of the cartridge.

In effect, by inserting the cartridge, the water paid for is now in storage, to be used at the consumer's discretion. When the faucet is open, water flows through the meter. Any movement of water through the meter sets the mechanism in action.

The mechanism is a water propelled driving assembly, which through a gear train (transmission box and metering gears) shown in Figures 6-8, rotates a dual purpose cam. The cam shown in Figure 9, holds open the valve and returns the piston to its starting position. When the cam completes one revolution, the valve will close and the mechanism comes

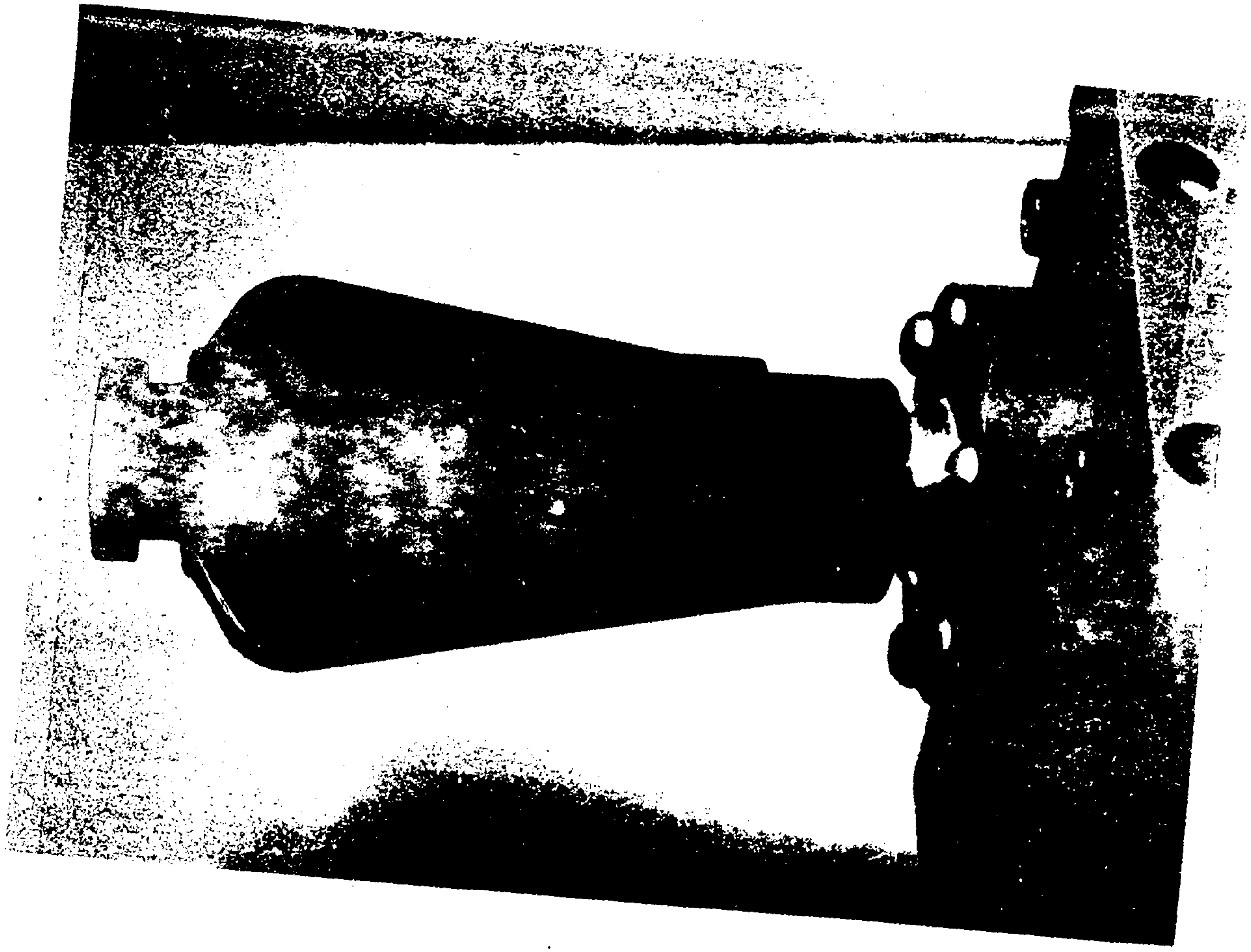


Figure 3: Breech Assembly

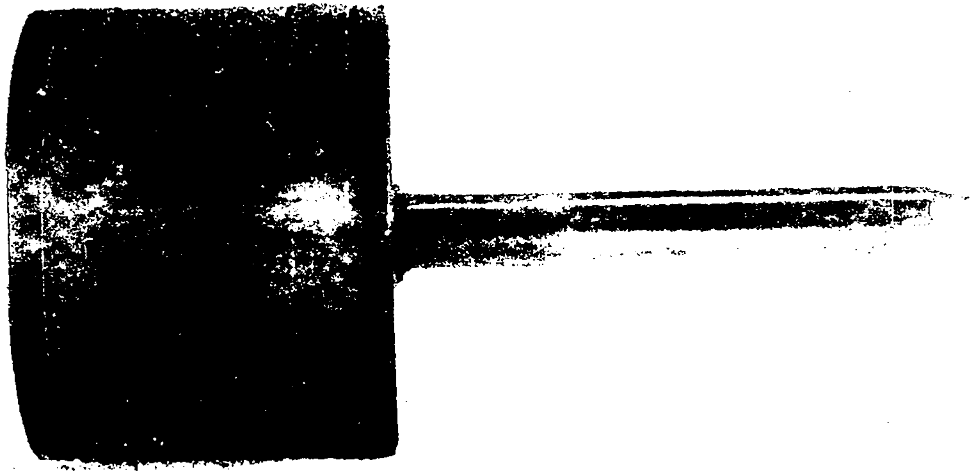


Figure 4: Piston Assembly Rings and Rod

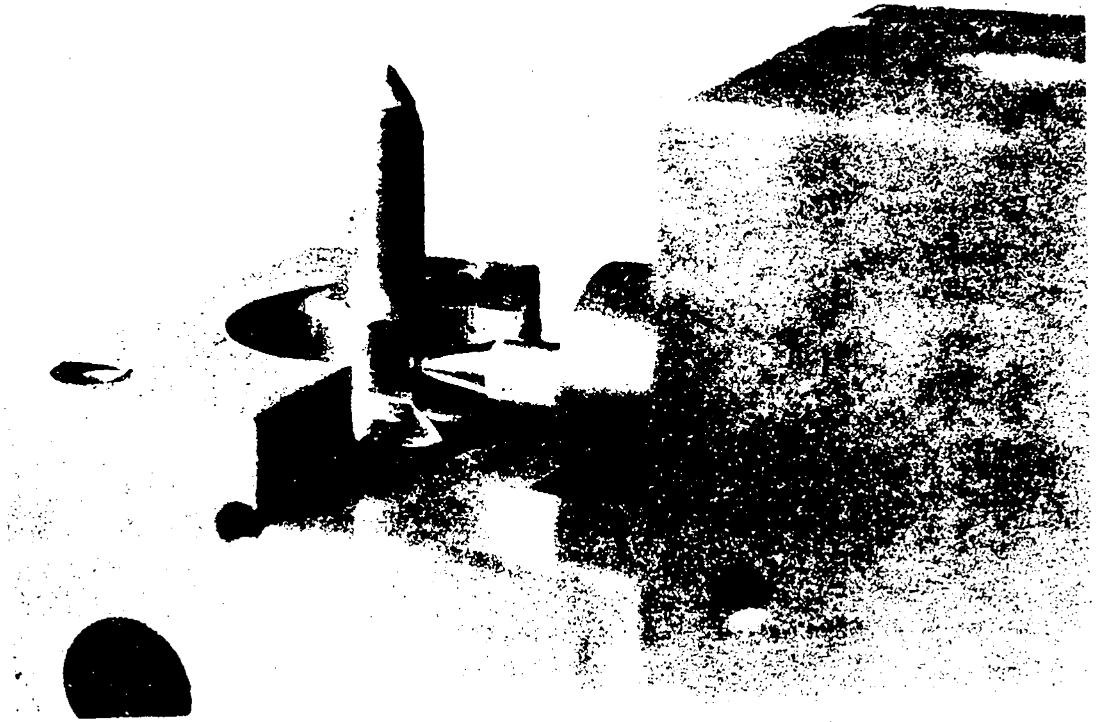


Figure 5: Valve Mechanism Showing Piston in Forward Position, Valve Stem Depressed

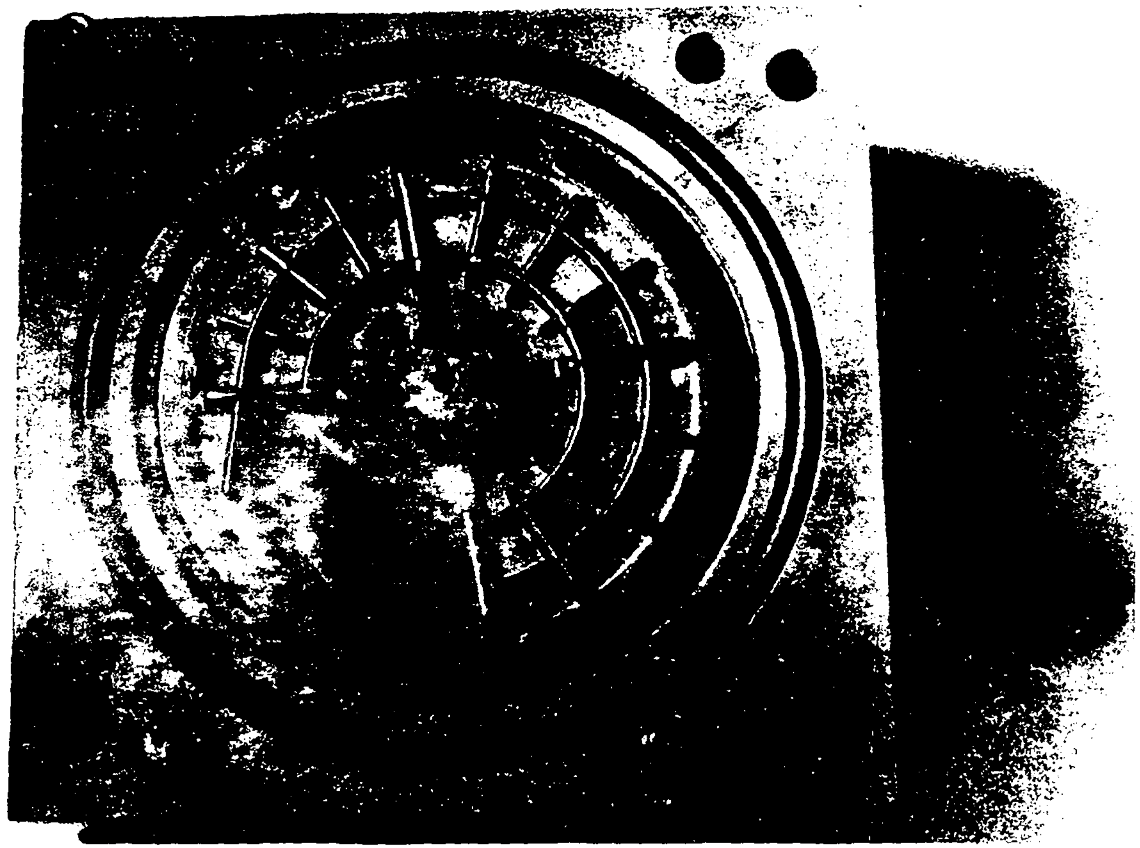


Figure 6: Driving Assembly (Rotary Piston)

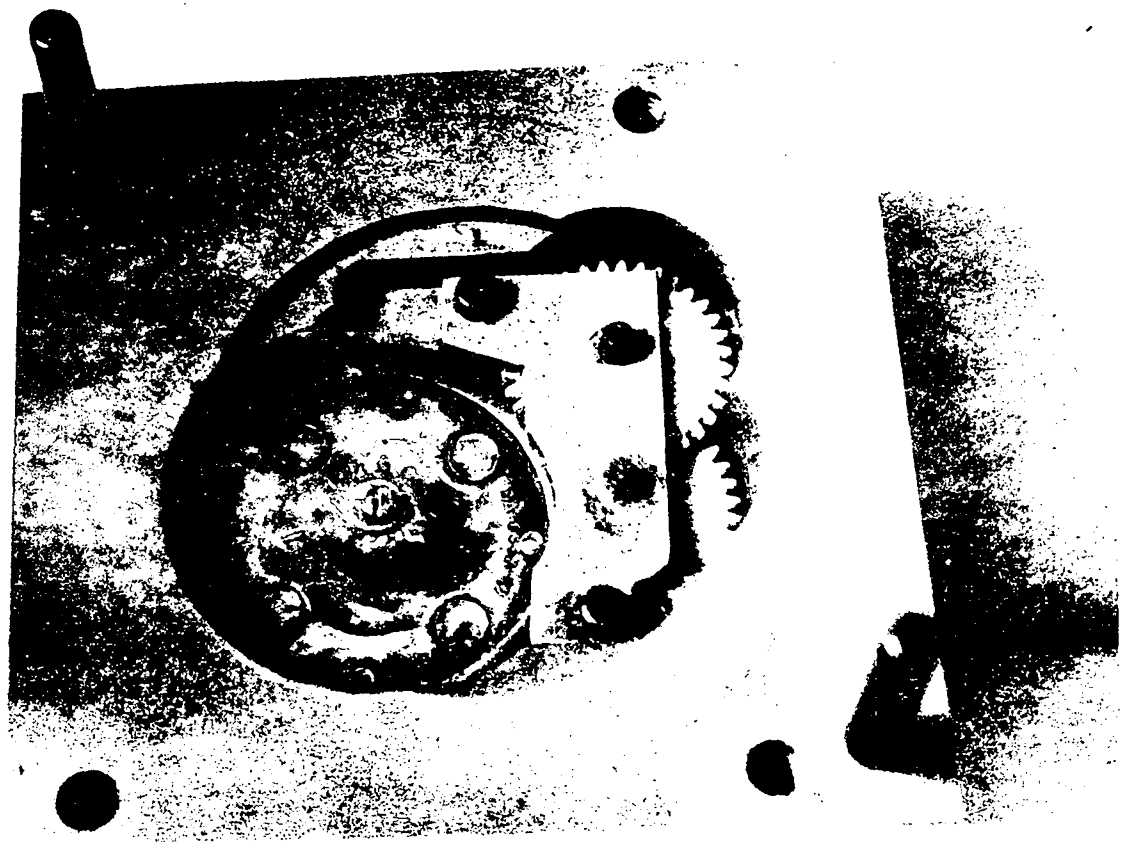


Figure 7: Transmission Box Showing Cluster Gears and Drive Pinion

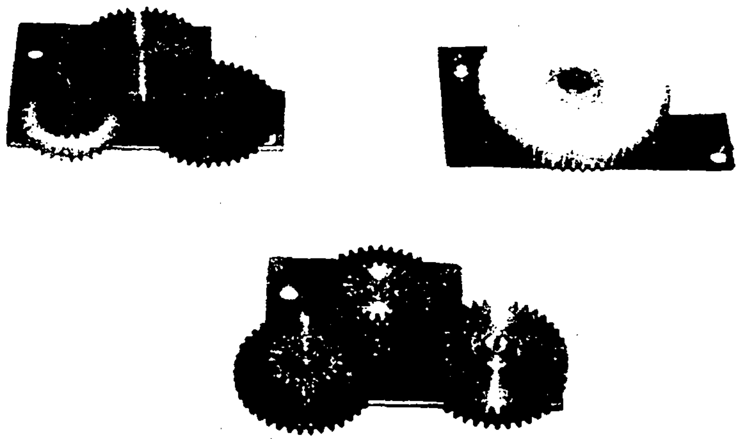


Figure 8: Metering Gears Showing Assemblies for Three Particular Volumes

Figure 9: Dual Purpose Cam

to rest, restricting further flow of water. This sequence is shown in Figures 10-12. It is now necessary to reactivate the meter with a fresh cylinder to obtain further water supply at the faucet.

The amount of water supplied per activating cylinder will be predetermined by the water utility and controlled by a simple gear train (Figure 8) preset at installation. Actual volumes will be determined based upon socio-economic conditions and technical considerations. Detail drawings of the meter are given in Appendix A.

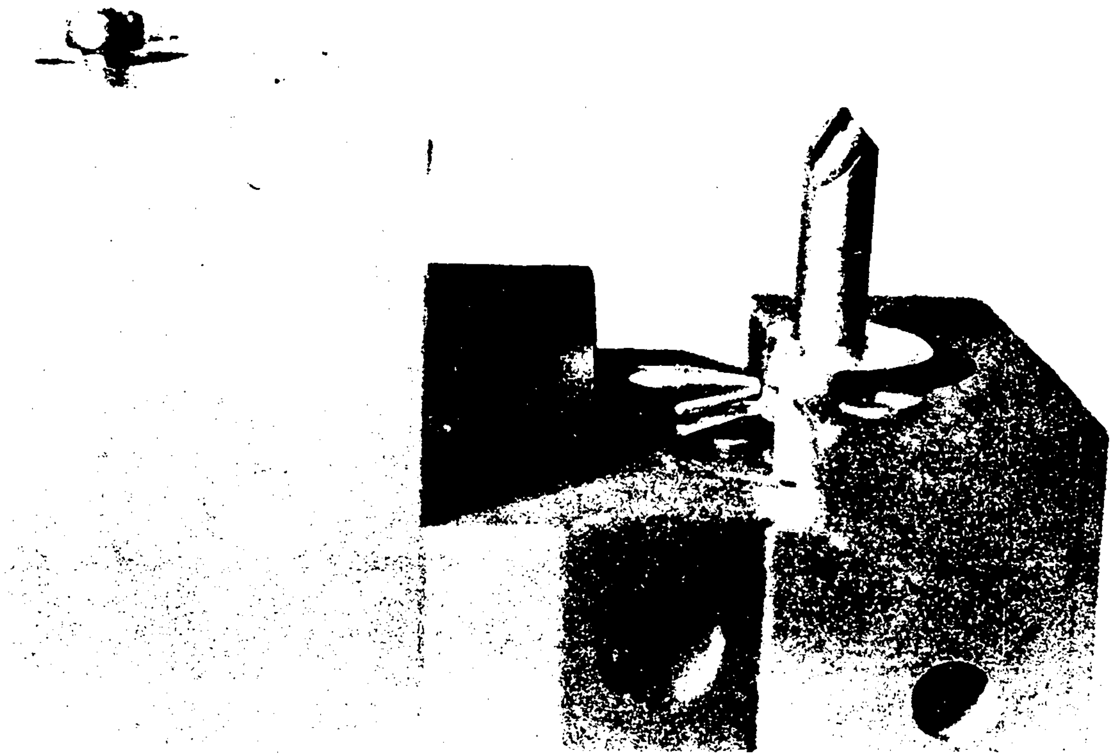


Figure 10: Valve Mechanism Showing Valve Stem Held Open by Vertical Acting Portion of Cam

Figure 11: Valve Mechanism Showing Horizontal Acting Portion of Cam Returning Piston Toward its Starting Position

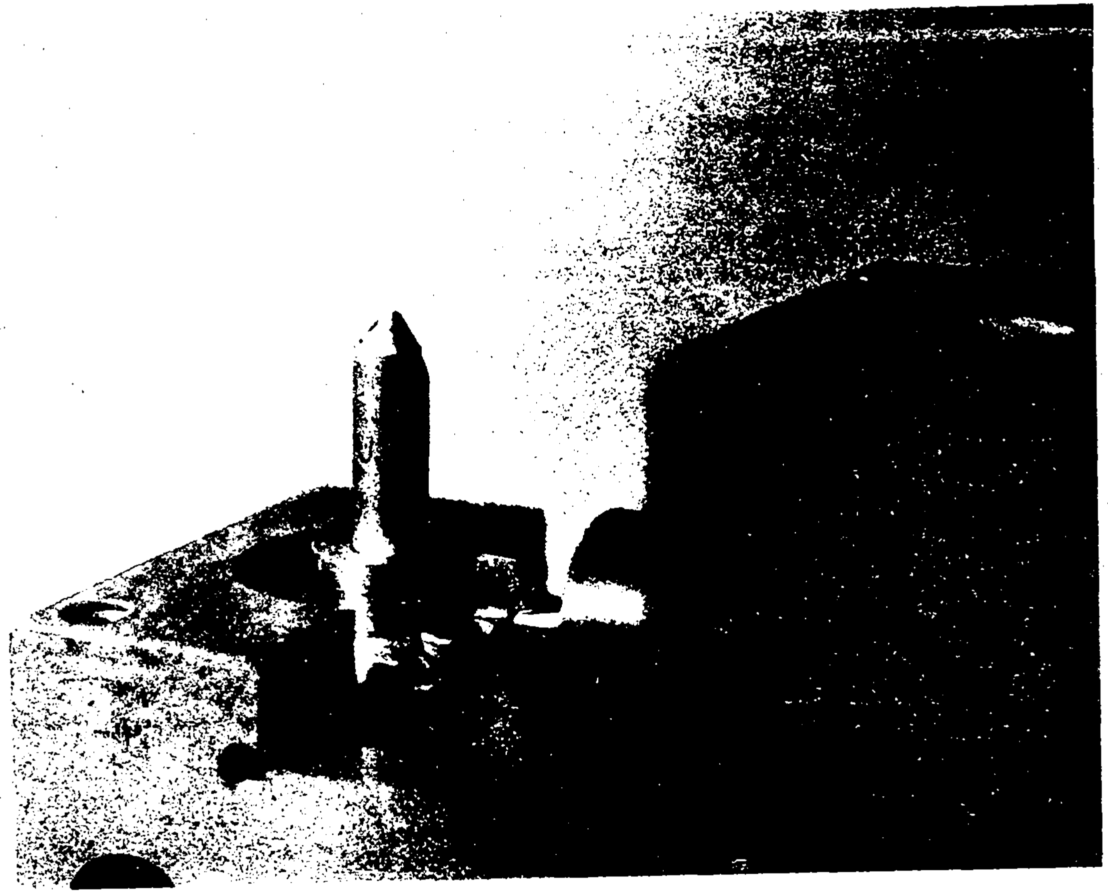


Figure 12: Valve Mechanism Showing Cycle Completed and Valve Stem Having Returned to Closed Position

# EXPERIMENTAL WORK

## Driving Mechanism and Power Train

The heart of the Robometer is the driving mechanism (Figure 6), i.e., the unit that converts part of the energy of the flowing water through the meter into the torque required to operate a gear train. Initially, an efficient driving mechanism which operates under a wide pressure range of 1 to 40 psi was sought. Review of the literature of water meter manufacturers indicated that the driving mechanism of most meters are either an oscillating disk, rotary vane, or rotary piston.

The oscillating disk in a common disk meter, oscillates in a passageway so that a known volume of fluid moves through the meter for each oscillation. A stem normal to the oscillating disk operates a gear train which in turn activates a counter.

In meters equipped with a rotary vane, the vane is driven by the water and it revolves in direct proportion to the quantity of water passing through the meter. The revolutions of the vane are transferred by appropriate reduction gears to a counter.

A volumetric unit operating on the rotary piston principle utilizes a piston which the water oscillates in a working chamber. Each piston cycle is equivalent to a known volume of water. The piston movement is transferred by appropriate reducing gears to a counter.

Experiments using representatives of each of the above driving mechanisms were conducted to determine the torque output of each of the above under various flow rates and pressures. It was concluded that the rotary piston driving mechanism was the most efficient unit providing the highest torque under low pressure and low flow conditions, which are common in most LDC's.

Various configurations of power train drives were investigated. The direct rotary motion of the rotary piston had to be stepped down to maintain sufficient torque to operate the cam which controls the movement of the piston and rod. Different combinations of plastic worm and wormwheel, as well as other power trains were tested. Of all combinations evaluated, the preferred power train is the one shown in Figure 7, comprised of a train of plastic cluster gears.

Piston and Cylinder

The first piston and cylinder assembly was constructed from metal. A number of tests on the forces developed on the piston rod when the cartridge is activated, i.e., gas is released from the cartridge to the piston, suggested that a smaller piston assembly constructed from PVC should function well. Therefore, a PVC piston and cylinder assembly was constructed and tested. To provide a seal between the piston and the cylinder, two rubber "O" rings were used. The PVC piston and cylinder assembly was subjected to 5,000 cycles of piston movement. The cylinder was stationary while the piston movement of 5 cycles per minute was provided by a mechanical arm linked to an electric motor via a series of pulleys. After 5,000 cycles only small wear of the "O" rings was noted. This wear did not affect the seal between the piston and the cylinder wall. It is interesting to note that if a meter was to be activated twice a week, 5,000 cycles is equivalent to 48 years of operation.

Further experimental work on the piston and cylinder assembly led to the replacement of the "O" rings with two PVC rings which provides an excellent seal.

## Air Relief Valve

Because it is not uncommon to have air in the distribution lines in many LDC's, an air relief valve was incorporated in the meter. The purpose of such a valve is to allow the air to escape before it reaches the driving mechanism, ensuring that the volume of water purchased will not be influenced by the air flowing through and rotating the driving mechanism of the meter.

The objectives in designing the air relief valve were to have a minimum of moving parts, and the ability to operate over a wide range of flow rates and pressures. The valve selected operates on the principle of buoyancy. As long as air is flowing through the incoming line, it will enter the valve and escape through the air vent; thus, the air flow will not activate the driving mechanism. As soon as the water arrives, the valve floats into place and seals the air vent, forcing the water to go through the driving mechanism of the meter.

## Metering Gears

The metering gears shown in Figure 8 are calibrated to dispense 1, 2, 3, and 4$m^3$. The above gears are interchangeable, thus giving the water authorities some flexibility to decide which gear arrangement is preferred, or to change the gears after the meters have been installed. A number of calibration tests were conducted at different pressures. The results, summarized in Table 1, show the accuracy of the meter under different operating conditions. The difference in volume dispensed in relation to line pressure can be attributed to the drop in efficiency of the driving mechanism at low pressures. The internal components of the meter have not been optimized, thus leading to large head losses. Significant improvements in meter accuracy can be expected after optimization.

## Cam Development

Development of the dual purpose cam was probably the greatest obstacle in the development of the meter. With certain physical restrictions (size and orientation), it was difficult to get an acceptable geometric pattern between the cam and piston rod. The ideal situation is when a tangent at the point of contact is close to (90°) to the piston rod.

It was discovered that any eccentric loading on the piston rod created a great deal of back pressure and when transmitted back into the driving mechanism, would cause jamming and sometimes shearing of the plastic gear teeth.

Experiments with bench models of different cam configurations led to the selection of the type of cam to develop and what functions it should perform.

The requirements of the cam are:

1. To hold in position the valve stem already depressed by the piston rod.

2. To return the piston and rod to the starting position.

3. At the completion of the cycle, to release the valve stem and thus allow the water supply to be cut off.

The first cam to be incorporated in a prototype meter under this project presented some problems. As it was attempted to return the piston and rod to the starting position with the cam lobe in contact for only 120° of rotation, and the above mentioned physical restrictions, difficulties were encountered with interfacing of components.

Expanding the scope of the cam and keeping contact with the piston rod for approximately 300°, therefore spreading the work to be done over a much longer period, improved the component interfacing action considerably. All that remained then was the timing between the horizontal acting portion of the cam (which returns the piston and the rod) and the vertical acting portion which holds open and allows the closing of the gate valve.

Having satisfied the conditions required, the cam was then incorporated in a prototype meter and has proved to be successful.

## ECONOMICS OF USER ACTIVATED WATER METER FOR UTILITIES AND CONSUMER

The water meter/box assembly would be manufactured in-country for about \$12.00/unit. Installation with LDC labor, including logistics, would cost about \$3.00 per unit. The utility would thus have a one time installed cost of \$15.00 per unit for the meter. No meter reading or billing costs would subsequently develop. Infrequent routine maintenance (estimated once every 4 or 5 years), which provides an outside inspection of the unit would be required.

The utility would price the cost of the cartridges in the following manner:

(a) The production, operation and maintenance cost per cubic meter would be established by the utility, i.e., say \$0.10 per cubic meter.

(b) Based on a consumer demand market survey, the utility would decide what volume of water they would require their meters to dispense. This would coincide with the ability of the people to afford such a volume within a certain time period, i.e., should the survey show that they use and can afford $2m^3$ every 3 days, the meter would be set to dispense $2m^3$ of water.

(c) Based on the cost per cubic meter established by the utility in (a) and the cubic meters to be dispensed per activation, the cost per cartridge to the utility would be the number of cubic meters dispensed times the unit cost of the water, i.e., for our example $2m^3 \times \$0.10/m^3$ or $\$0.20/2m^3$ cartridge plus the cost of the manufacture and filling of the 10 ml-860 psi cartridge (c 1.5 to c 2.0 per cartridge). A pass-through charge of 2-3 cents per cartridge would be provided to commercial stores for handling and having readily available such cartridges for the consumers to buy. The total cost to the consumer would be as follows:

for 1 cubic meter volume cartridge -
$\$.10 + .03 = \$0.15/m^3$

for 2 cubic meter volume cartridges -
$\$.20 + .02 + .03 = \$0.25/2\ m^3$ or $\$0.125/m^3$

for 3 cubic meter volume cartridges -
$\$.30 + .02 + .03 = \$0.35/3\ m^3$ or $\$0.112/m^3$

for 4 cubic meter volume cartridges -
$\$.40 + .02 + .03 = \$0.45/4\ m^3$ or $\$0.112/m^3$

for 5 cubic meter volume cartridges -
$\$.50 + .02 + .03 = \$0.55/5\ m^3$ or $\$.110/m^3$

for 10 cubic meter volume cartridges -
$\$1.00 + .02 + .03 = \$1.05/10\ m^3$ or $\$0.105/m^3$

A summary of the costs to consumers using the Robometer system is given in Figure 13. It should be noted that the cost of marketing (on a unit cost basis) is nominal for volumes greater than $1m^3$. Essentially, it results in a $\$0.01$-$\$0.02/m^3$ increase in unit costs to the consumer.

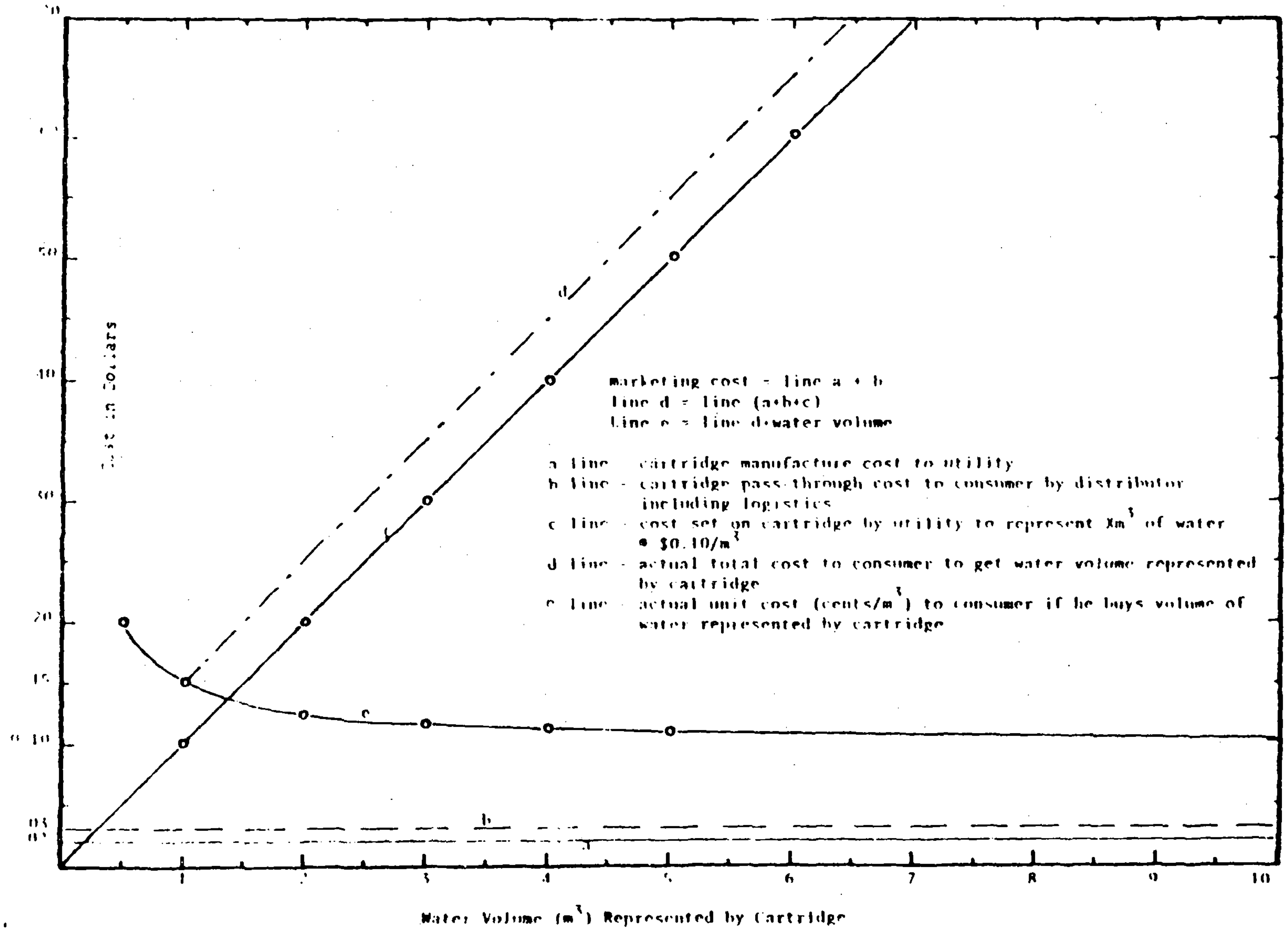



Figure 13: Projected Water Costs Using Robometer

## CONCLUSIONS AND RECOMMENDATIONS

The goal of this project has been achieved by developing a new user activated water meter, made almost entirely of thermoplastic materials. The meter is a non-proprietary item directed toward local production in LDC's. The activating device of this meter is a small compressed air cartridge. Although the technology and equipment for manufacturing and recharging the cartridges is available, costs for setting up a plant are difficult to obtain.

Activation of the meter is achieved by inserting the "one-shot" cartridge into the meter. The meter can be set by the water utility company to dispense from $1m^3$ to $4m^3$ of water using interchangeable gears. The consumer, by purchasing and using the activator, has prepaid for the water and can use it at the time of his choice.

The meter is viewed as a key component in a new marketing and water metering system in which the water utility company is assured of receiving revenues subject to minimal collection costs. Guaranteed revenues should influence favorably the planning of utility companies with regard to expansion of water services to poor sections or communities.

The main subsystems of the meter are: the air relief valve, the driving mechanism, piston and cylinder, metering gears, valve assembly and dual purpose cam. While some of these subsystems were developed and perfected experimentally via a trial and error procedure, others were available commercially and required only slight modification.

The prototype meter has been subjected to only a limited amount of laboratory tests and further laboratory and development work are necessary. In particular it is recommended that:

1. A follow-up project incorporating further laboratory development and testing be undertaken. The specific objective of such a project would be:

   (a) Development of a meter box and locking devices for the meter

   (b) Determining the wear and behavior characteristics of each of the subsystems of the meter utilizing water of varying qualities.

   (c) Modification and adaptation, if necessary, of the present prototype design based on the information obtained from (a) and (b).

2. Evaluate the feasibility of producing the meter in selected LDC's based on present availability of equipment and technology. This phase should proceed simultaneously with recommendation (1) to ensure that the meter developed is compatible with the technology and resources available in the selected LDC's.

3. Evaluate the costs associated with setting up a cartridge recharging facility in selected LDC's.

4. Subject the meter to an extensive field testing program in order to:

   (a) Evaluate the behavior of the meter under LDC consumer use.

b) Evaluate the acceptability of the meter by LDC consumers of different cultures.

(c) Work with interested national governments and local plastic manufacturers to stimulate local production of meters and cartridges.

(d) Modify and adapt, if necessary, the design based upon the information obtained from (a), (b), and (c).

TABLE I

ROBOMETER CALIBRATION TESTS

| PRESSURE, PSI | GEAR ASSEMBLIES | | | |
|---|---|---|---|---|
| | 1 $m^3$ | 2 $m^3$ | 3 $m^3$ | 4 $m^3$ |
| 5 | 1.12 | 2.25 | 3.35 | 4.46 |
| 10 | .99 | 1.99 | 2.98 | 3.98 |
| 20 | .99 | 1.99 | 2.99 | 3.98 |
| 40 | .95 | 1.89 | 2.94 | 3.90 |

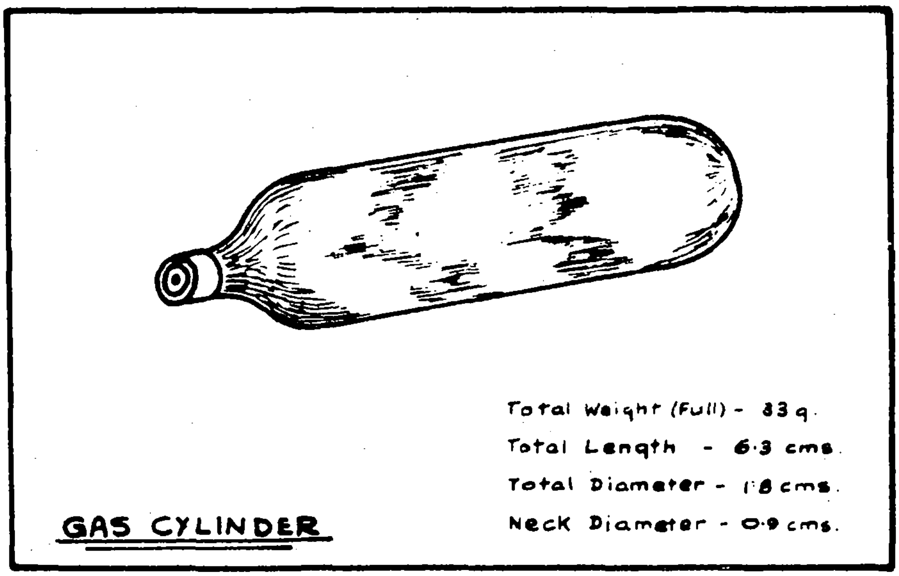
Each data point (given in $m^3$) represents an average of three tests.

# APPENDIX A

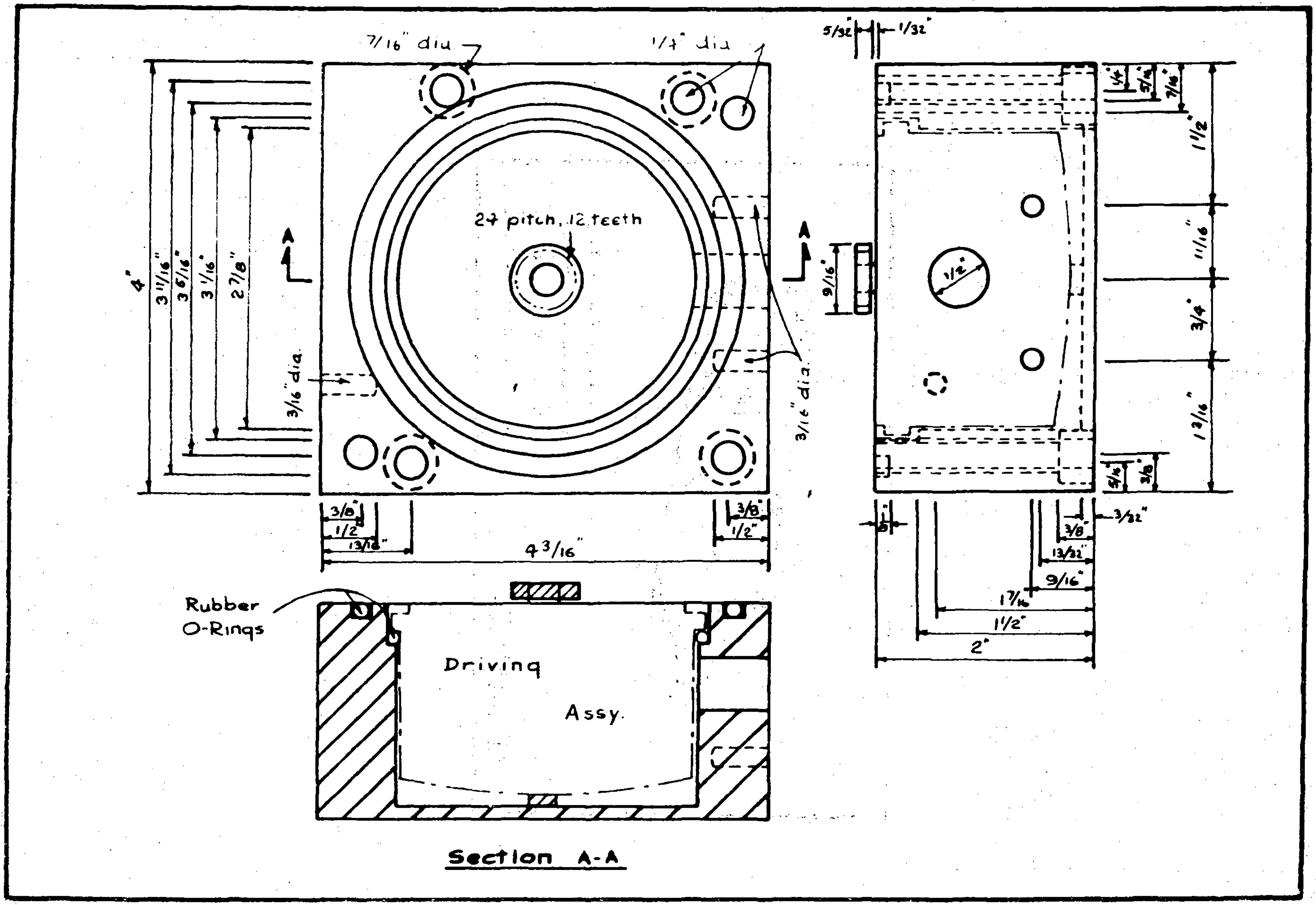
## WORKING DRAWINGS OF ROBOMETER

Note: All drawing dimensions are as shown

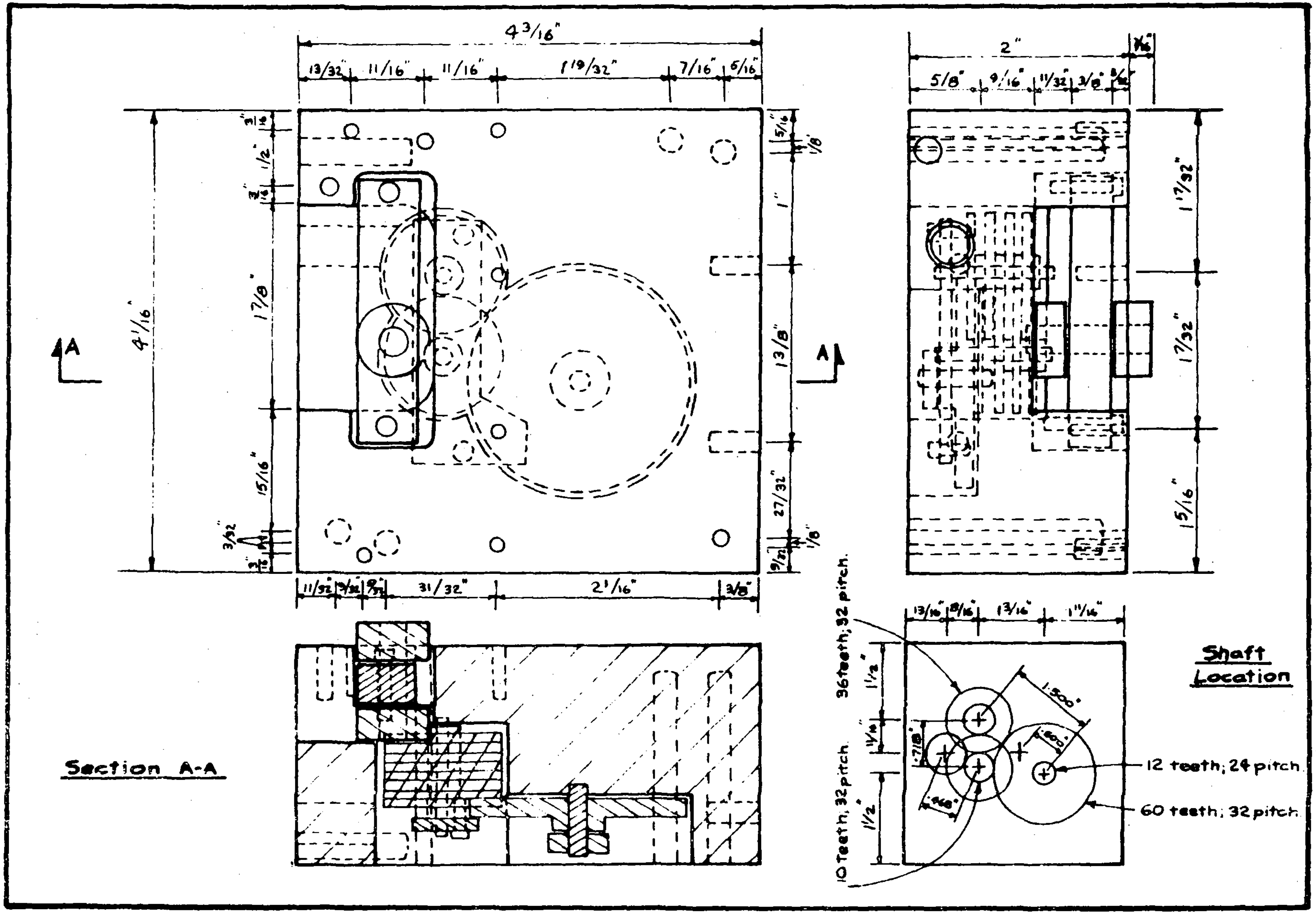
## LIST OF FIGURES



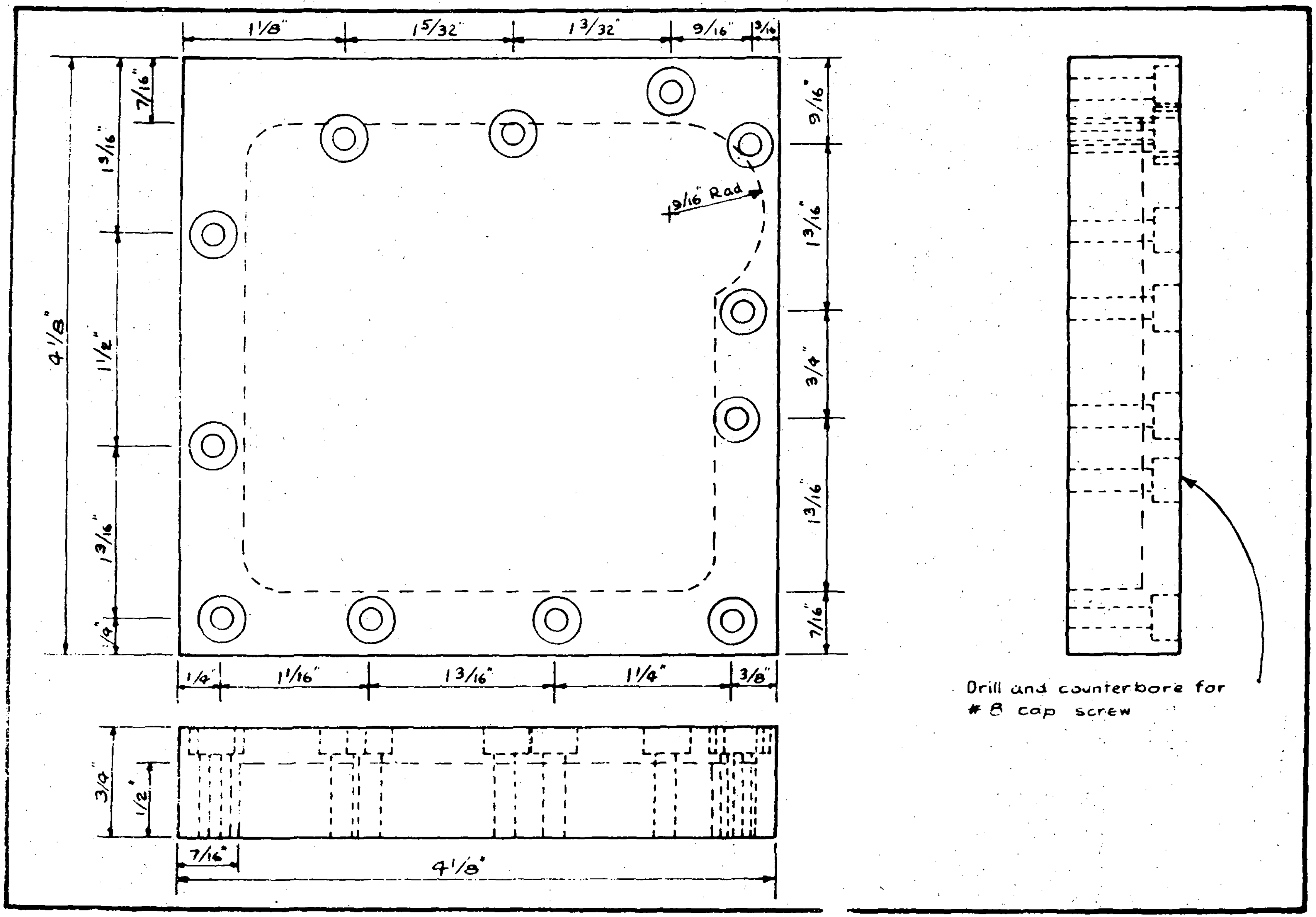

A-1. Compressed Gas Cylinder



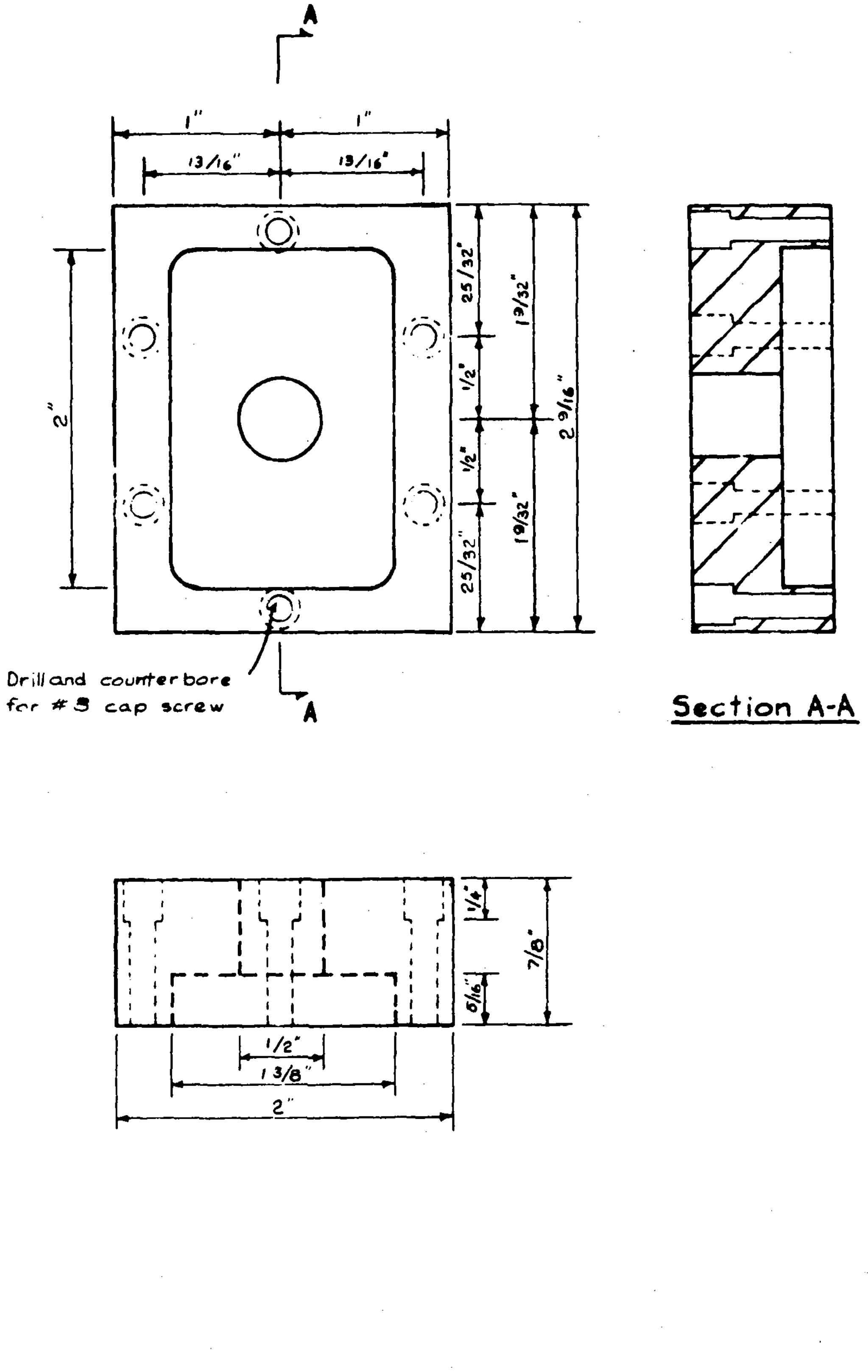

A-2. Driving Unit



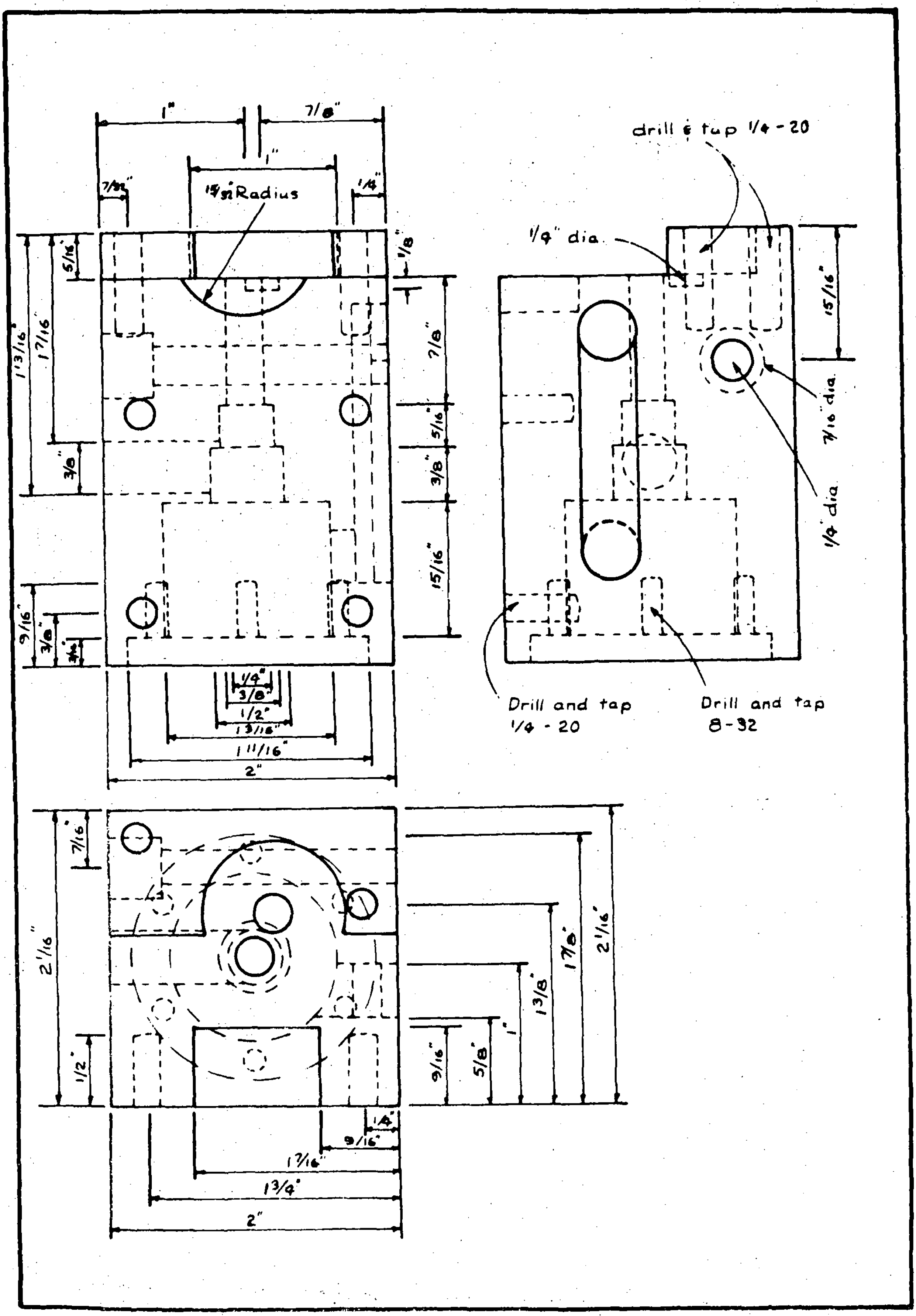

A-3. Transmission



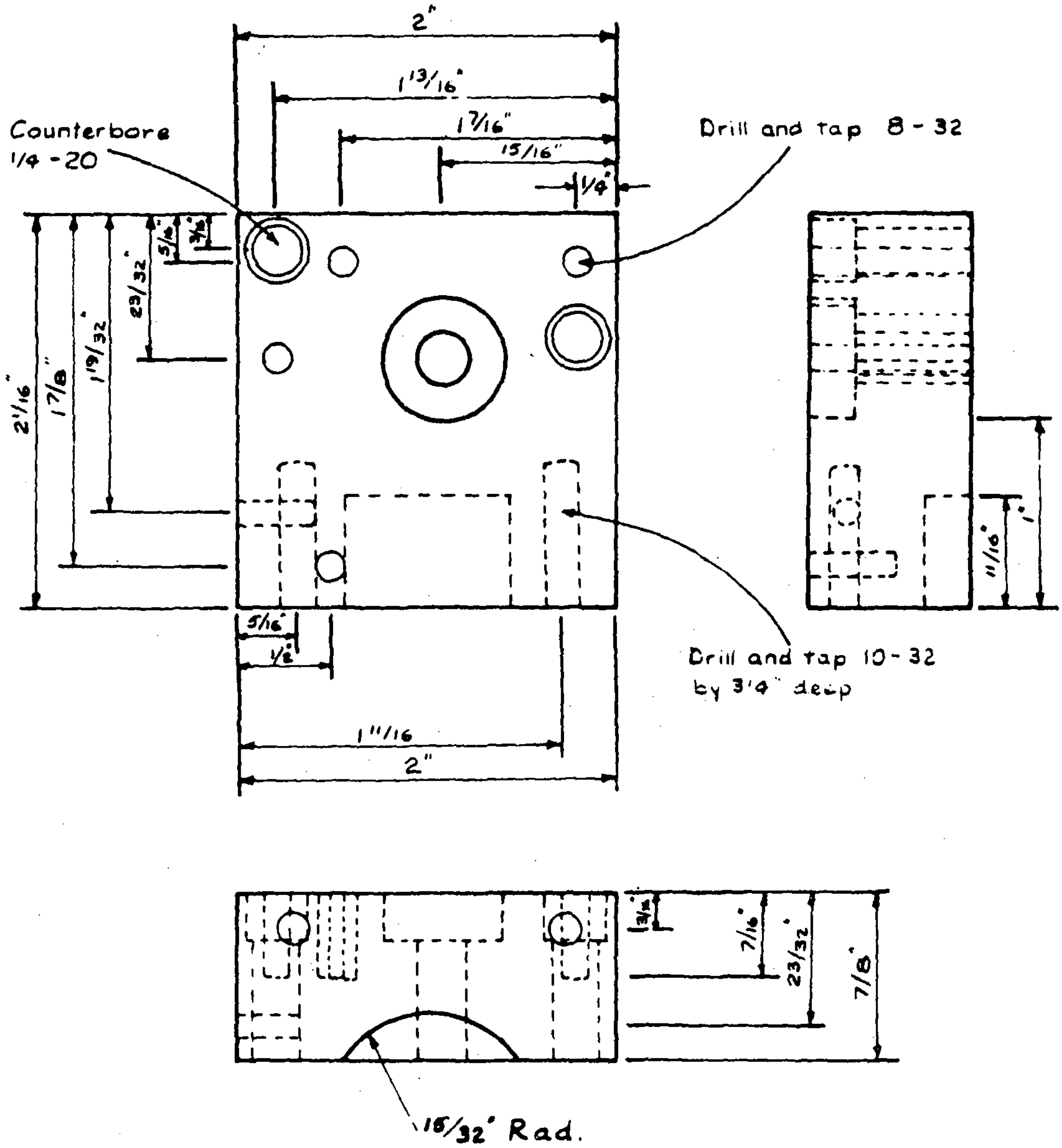

A-4. Metering Plate Cover



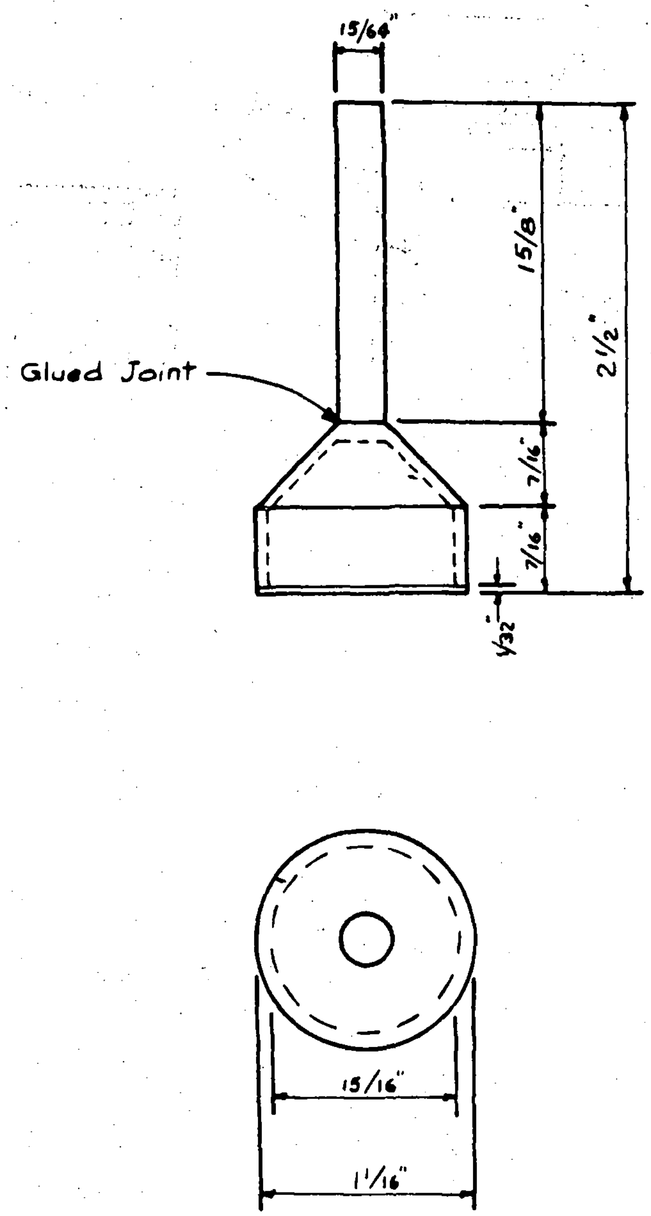

A-5. Outlet Port



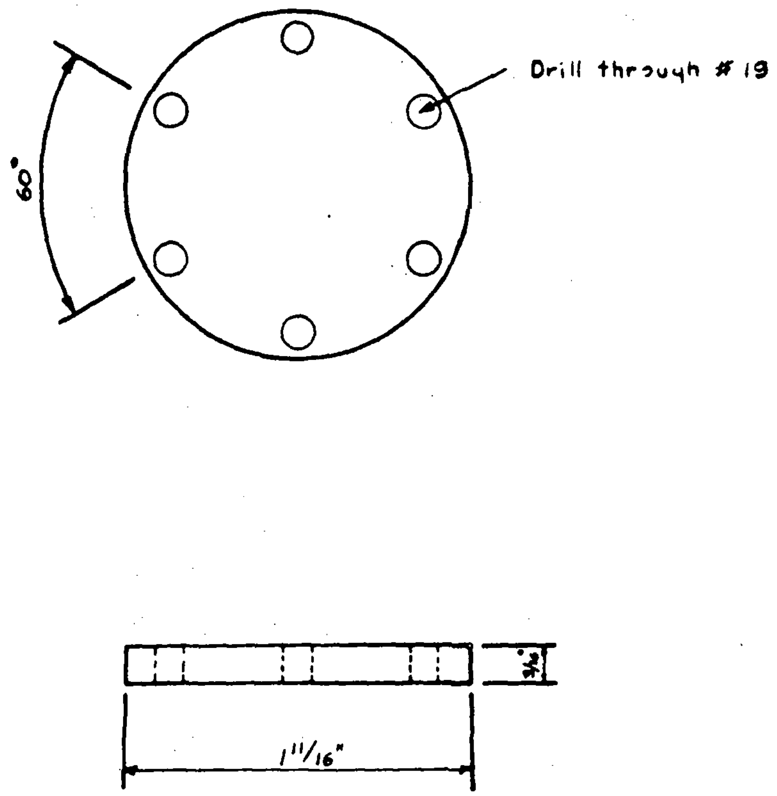

A-6. Gate Valve Housing



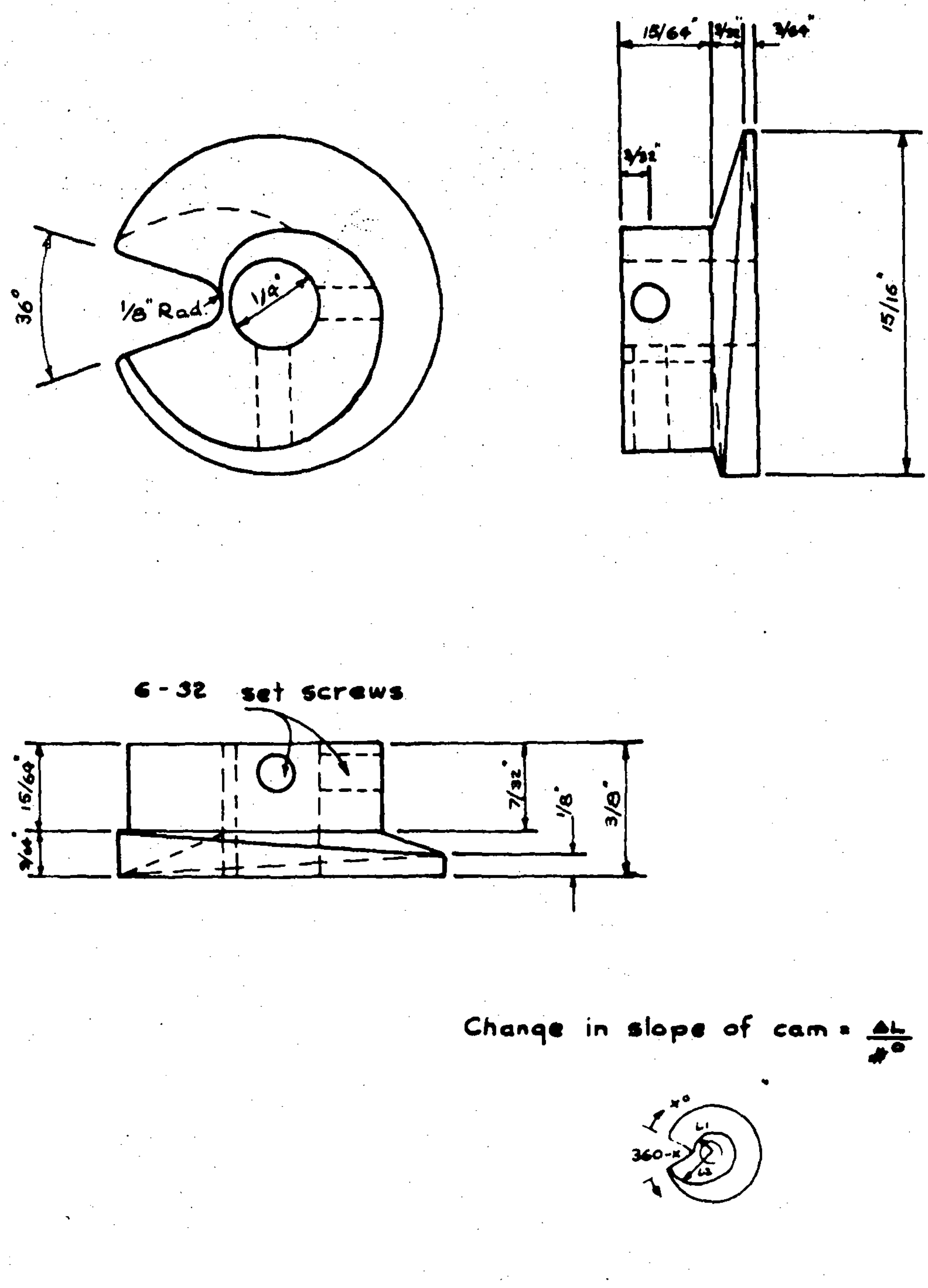

A-7. Cam Drive Support



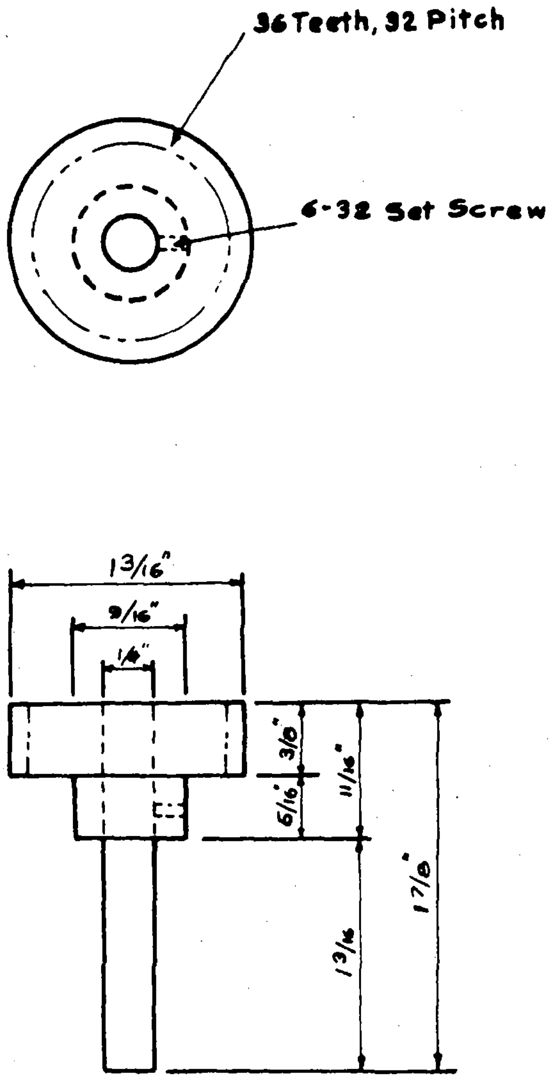

A-8. Valve Core



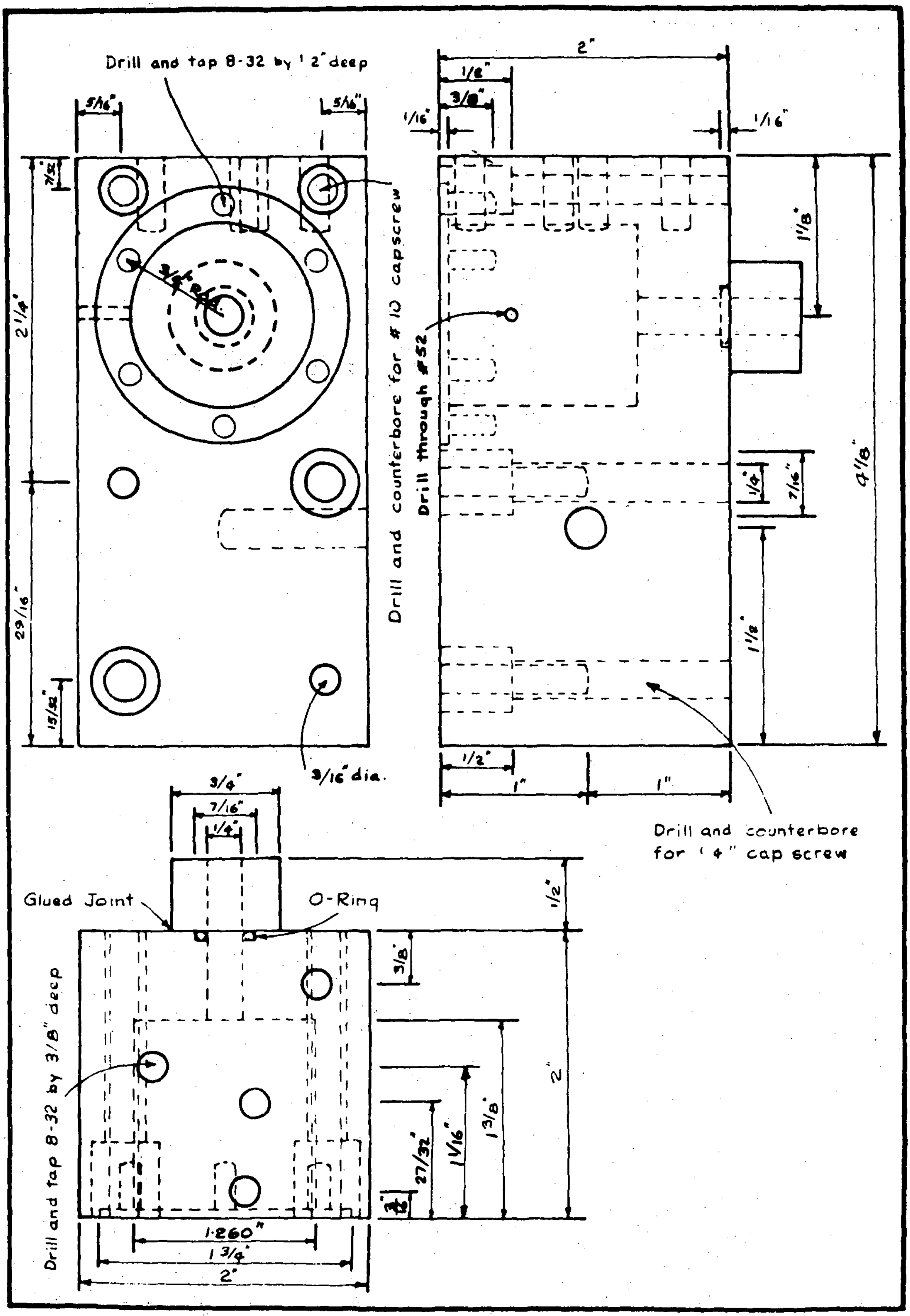

A-9. Valve Cover



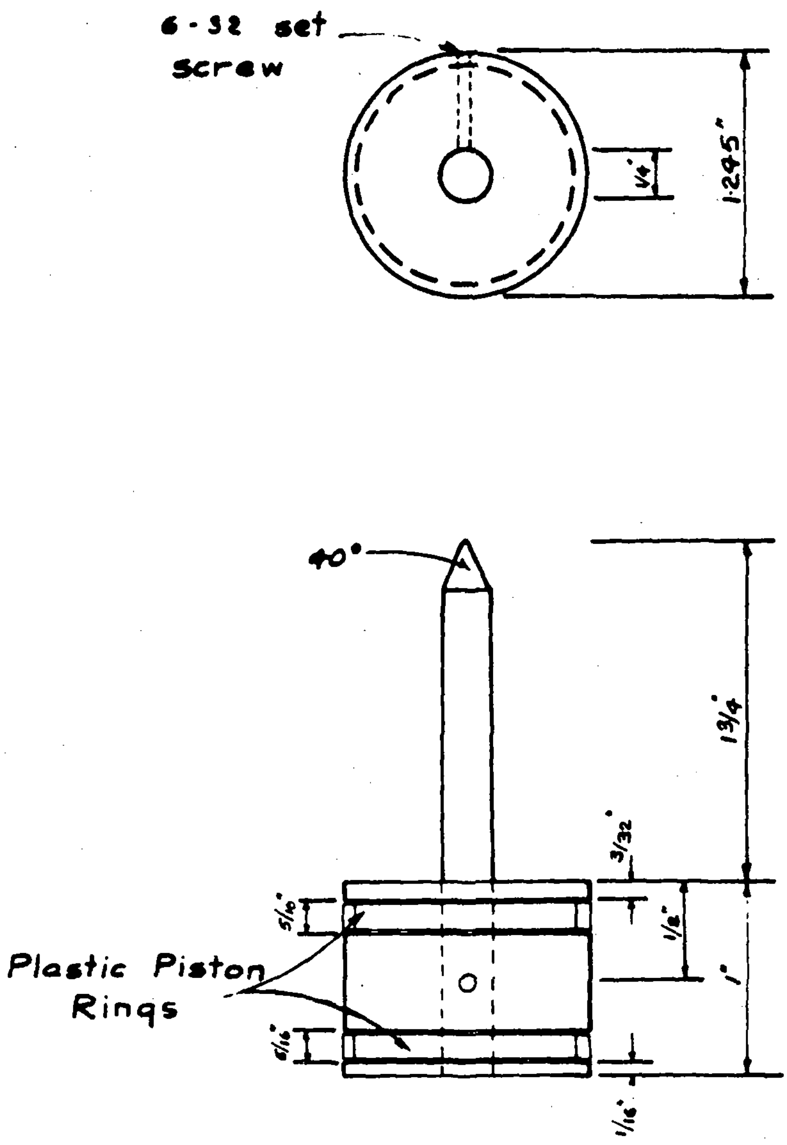

A-10. Dual Purpose Cam



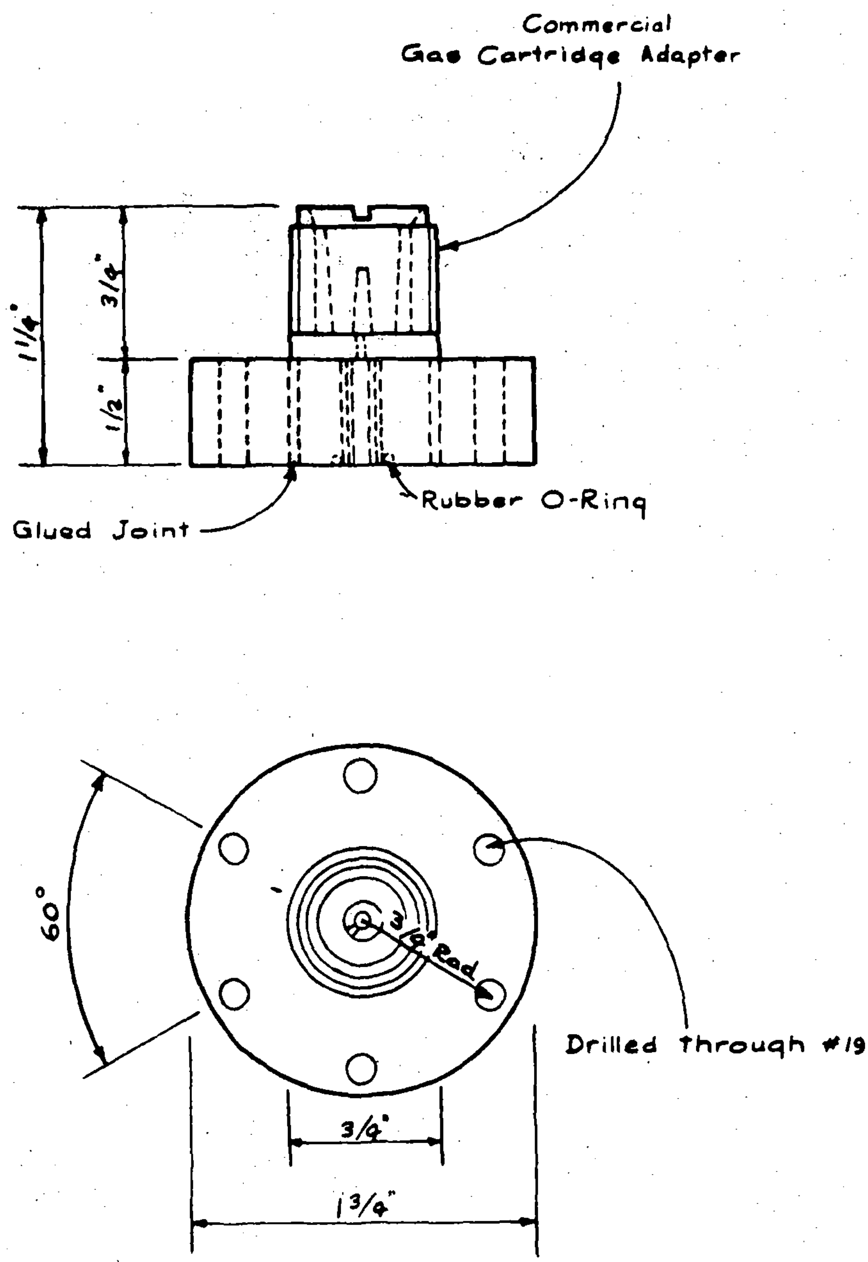

A-11. Camshaft



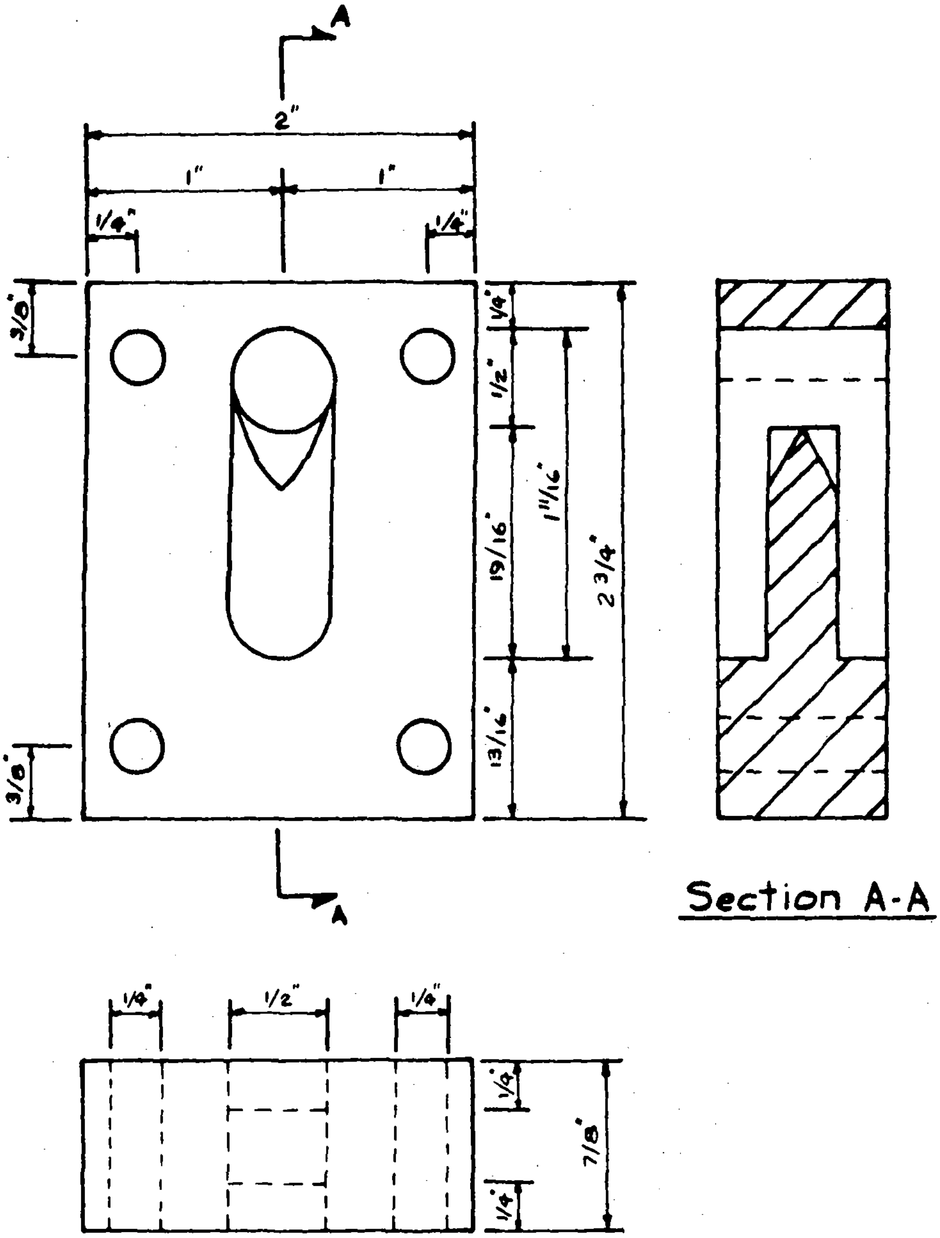

A-12. Cylinder Block



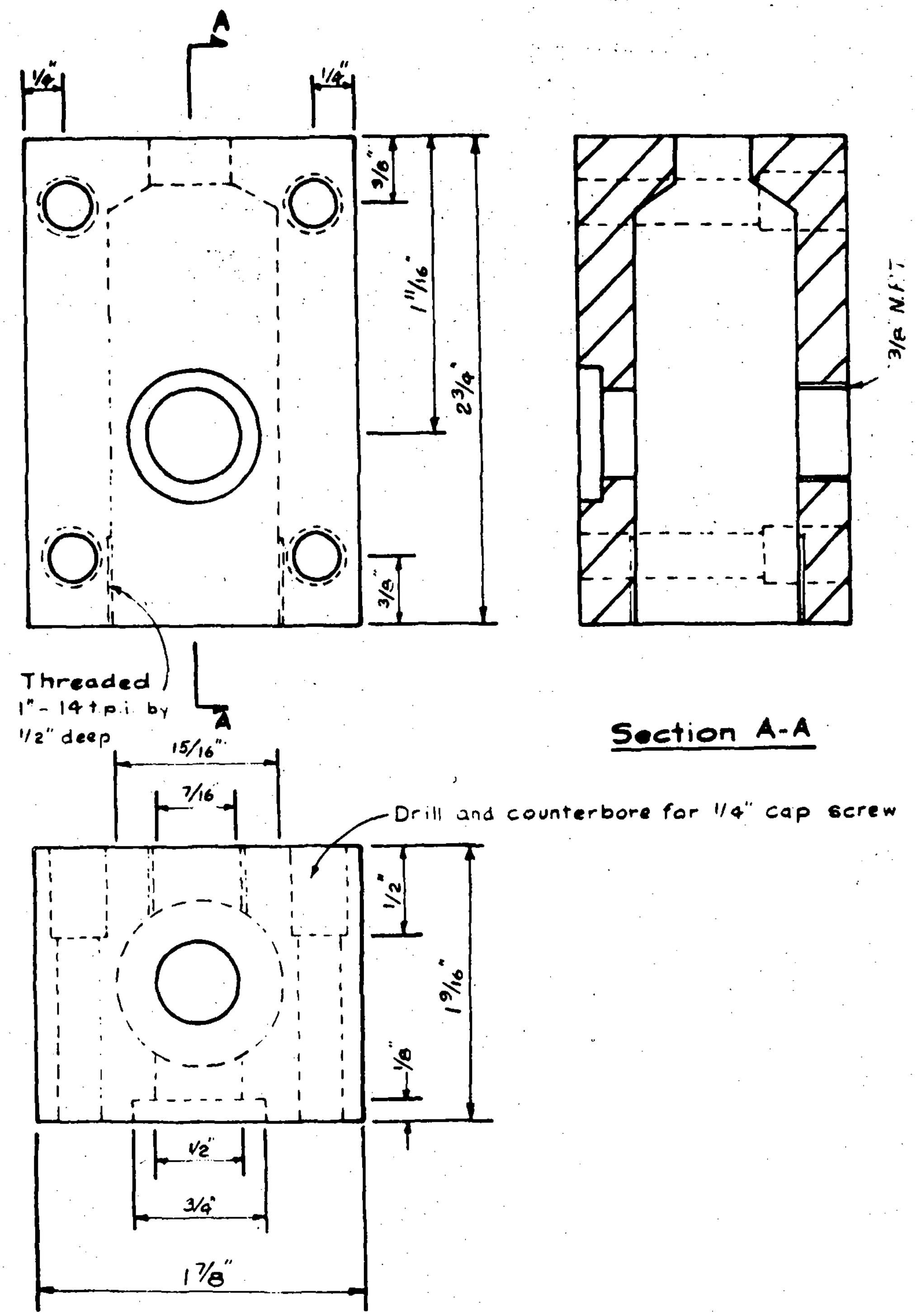

A-13. Piston and Rod



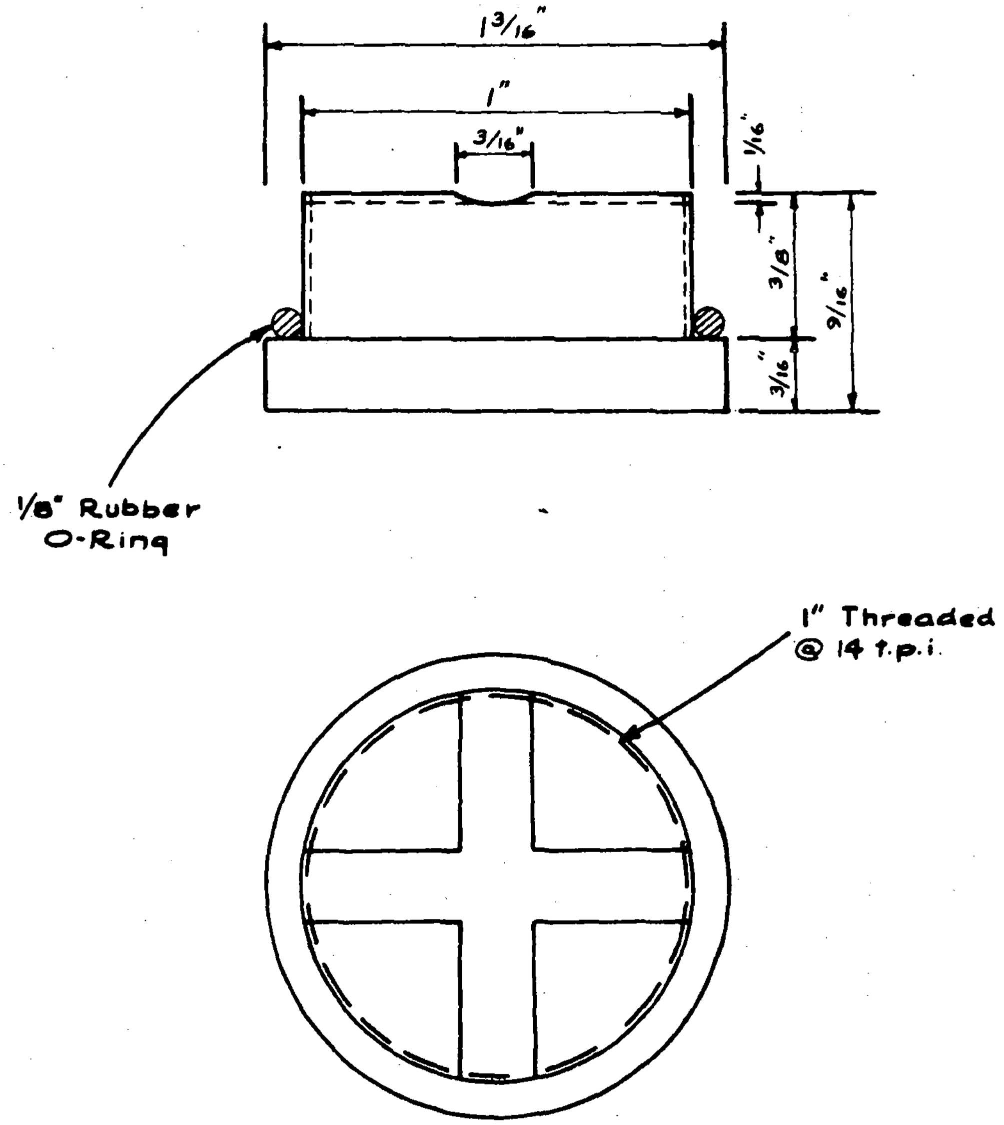

A-14. Gas Cartridge Recepticle



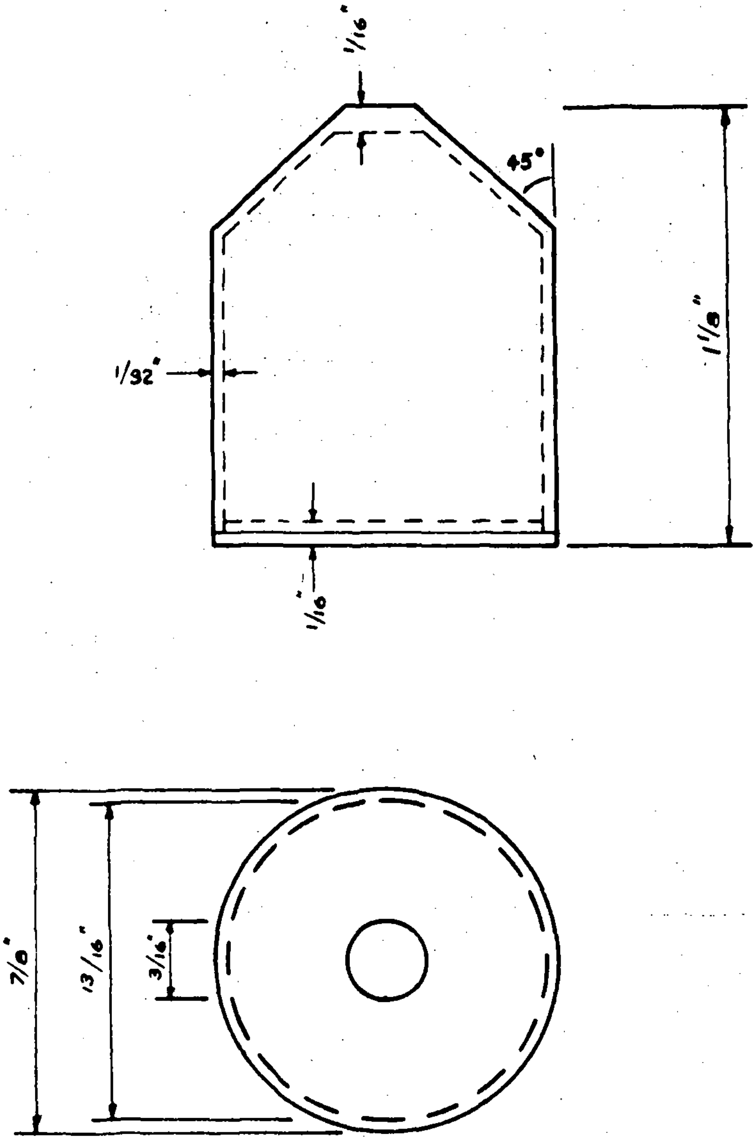

A-15. Flow Deflector



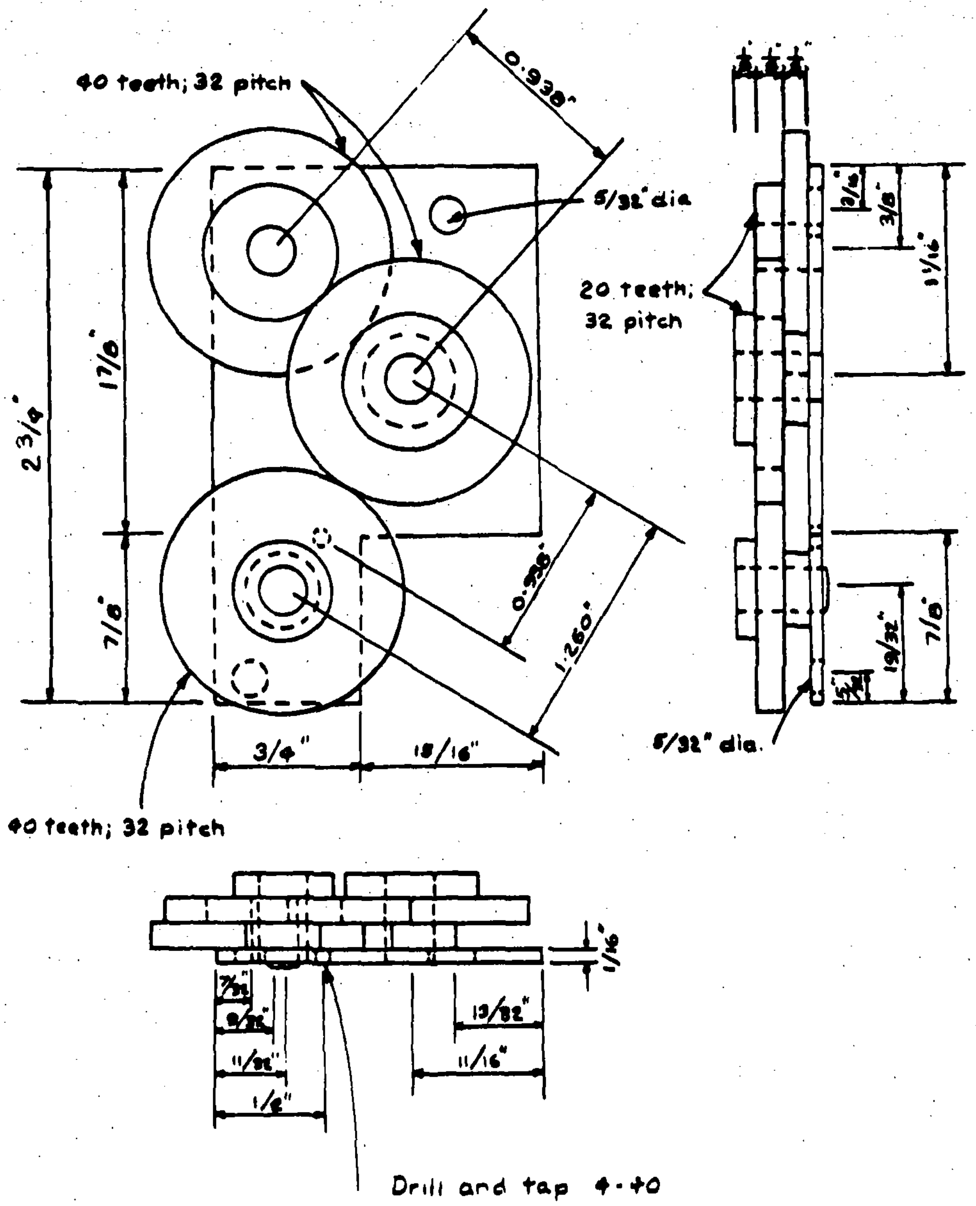

A-16. Air Relief Valve




A-17. Cap




A-18. Float




A-19. Metering Plate