January 1985

Water Well Pump Efficiency Monitor Units

Calvin G. Clyde
Duard S. Woffinden
Graeme Duncan

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WATER WELL PUMP EFFICIENCY MONITOR UNITS

by

Calvin G. Clyde,
Duard S. Woffinden,
and
Graeme Duncan

HYDRAULICS AND HYDROLOGY SERIES
UWRL/H-86/01

Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

November 1985
ACKNOWLEDGMENTS

This project was a cooperative effort of the Utah Water Research Laboratory of Utah State University and the Agricultural Research Service of the U.S. Department of Agriculture, Kimberly, Idaho. Most of the funds for the work were furnished by USDA-ARS. The contribution of Dr. Allan S. Humpherys, the project monitor for ARS, is gratefully acknowledged. His many constructive suggestions and patience are much appreciated.

During the course of the project Duard S. Woffinden, one of the authors, passed away. His contributions to the success of this and many other projects at UWRL will long be remembered. This volume is dedicated to his memory.

Calvin G. Clyde
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CHAPTER I
INTRODUCTION

The Problem and Opportunity

As the costs for pumping municipal, industrial and irrigation water rise, owners and the public are giving increased attention to energy conservation. One way to conserve energy is to operate water pumps at or near peak efficiency. The measurement of pump efficiency usually requires special test equipment, a skilled operator and time to perform the test. Owners may find it more economical to waste power than to monitor for inefficiencies. One way to help change this situation is to develop inexpensive equipment for unskilled people to use to obtain rapid measurements of pump efficiency under typical operating conditions. Such equipment would enable pump owners to find out quickly when their equipment was operating below maximum efficiency so the problems could be corrected. Prudent and timely maintenance work would pay off by making the pumping operation more economical and conserving energy resources.

Objectives and Scope

The general objectives of this project were to develop, fabricate, install, field test and evaluate low and medium cost pump efficiency monitor units for use by owners, operators or consultants. The low cost unit utilizes a "pitot" type flow rate meter while the medium cost unit includes an ultrasonic doppler type strap-on flow meter. Both units require simple computations to be done by the non-skilled operator using a hand held calculator. Recommendations for winter operation of the units were to be considered.

In a second phase of the study the objectives were enlarged to include experimentation with new flow rate measurement devices and the development, fabrication, installation, and testing of a totally automatic unit which requires no operator computations and has a timer and printer for recording the pump efficiency data.

This project report describes the pump efficiency monitors that were built as well as their installation, testing and evaluation.
CHAPTER II
WATER WELL PUMP EFFICIENCY MONITOR UNIT COMPONENTS

Overall System

Determining water well pump efficiency requires the measurement of three quantities: the flow rate, Q, in cubic feet per second (CFS); the pump lift, Ep, in feet (FT); and the input power, Pin, in kilowatts (KW) are shown in Figure 1. From these quantities the pump efficiency, E, in percent can be easily calculated from:

\[
P_{\text{out}} = 0.0846 \times Q \times E_p \quad \text{[KW]} \quad (2)
\]

\[
P_{\text{lift}} = E_p = H + \frac{V^2}{2g} + 2.31 \times (P_L - P_B) \quad \text{[FT]} \quad (3)
\]

\[
V = \frac{Q}{A_L} \quad \text{[FPS]} \quad (4)
\]

Where:

- \(H\) = vertical distance from center of delivery line pressure gage to the bottom end of the bubbler tube in the well.

The computation can be easily done by an untrained person using an inexpensive hand held calculator by following a simple set of instructions.

While the overall concept of pump efficiency measurement is simple, some of the parameters may be either difficult or costly (or both) to measure in existing pump installations where provision has not been made beforehand for the necessary instruments. Ideally, the measurement should be done with inexpensive, portable equipment that requires no alterations in the system, little time to set up and also requires little training to operate. Such ideal conditions are never met in practice—especially at low cost. There are always tradeoffs to be considered; between portability and permanence, among accuracy, precision and cost; between summer and all season operation; between systems requiring piping alterations and those that are non-invasive; and between automatic and manually operated systems, etc. Actually, cost is a prime consideration in all the tradeoffs listed above as well as others not mentioned.

Usually the measurements of pump efficiency has required the use of several special purpose tools and instruments by a highly trained expert over several hours time for each measurement. The technology may now be at hand to package the required instruments.
Figure 1. Pump efficiency measurement system components.
for pump efficiency measurements in one
box at a mass production price low
enough to be attractive to the pump
owner. Installation and checkout
should still be done by an expert, but
the system could be attractive to the
owner provided operation was either
automatic or required only a semi-
skilled, non-technical person for
routine use.

In this part of the report the
major components of the pump effi-
ciency monitor unit are discussed,
the various alternative devices are
described and those selected for use in
the prototype production models are
given.

Flow Rate Measurements

Devices considered for measuring
the flow rate were pitot tube devices,
ultrasonic flow meters, other miscella-
neous commercial flow meters (such as
orifice plates, venturi meters, prop-
eller meters, magnetic meters, etc.)
and experimental equipment using injec-
tion of salt, dye, heat, or some other
tracer to measure the flow rate.

Pitot tube devices. These instru-
ments consist of a special tube inserted
into the pipe. Inside the tube are two
separate chambers. From one chamber one
or more holes exit in the upstream
direction and from the other chamber a
hole exits downstream. The difference
in pressure between the upstream and
downstream ports is related to the
velocity in the pipe by:

\[ V = K \sqrt{\Delta h_w} \quad \text{[FPS]} \]  

(5)

where \( \Delta h_w \) is the pressure difference
between the two ports (usually measured
in inches of water). \( K \) is a constant
depending on the location of the ports,
the shape and size of the tube, the size
of pipe, kind of fluid, the shape of the
velocity distribution, the Reynolds
number and back pressure conditions.
For standard conditions \( K \) is determined
by calibration done by the manufacturer.

For standard installation with a
straight, uniform approach pipe of at
least 10 diameters upstream, the
manufacturer's \( K \) will give good results.
For locations that are non-standard (low
downstream pressure, nearby elbows,
valves or branches closer than 10
diameters upstream) the pitot type meter
must be calibrated in place to give
accurate measurements.

Many brands of pitot tube devices
are available. The Utah Water Research
Laboratory has used and calibrated many
of these, such as Accutubes, the Annu-
bars and Collins meters. An Accutube
and an Annubar were selected for use
with two of the units developed by this
project. They were calibrated at the
UWRL for standard approach conditions.

Pitot tube meters have the advan-
tages of availability and low cost,
but the disadvantage of requiring a hole
to be drilled in the pipeline and a
threaded fitting must be welded in
place.

Ultrasonic meters. These meters
are a relatively new development in
flow measurement technology. While
early models were quite expensive,
costs have come down and reliability and
precision have improved. Two types are
commonly available from many manu-
facturers—the dual path and the doppler
strap-on types.

The dual path ultrasonic meter
requires either a special pipe spool
with transducers already installed or
the two transducer mounts must be
welded to the existing pipe diagonally
across along a line at 45° from the
centerline. Ultrasonic signals are
beamed from one transducer to the
other in both upstream and downstream
directions. The downstream signal
is speeded up by the flowing water and
arrives early while the upstream
signal arrives late. Comparison of the
travel times enables computation of the flow velocity. The required
circuits are complex and expensive
and installation costs are high but the device gives accurate and precise results with good reliability in both clean and somewhat dirty water. Because of the meter costs and the permanent installation required, this meter type was not considered appropriate for most pump efficiency units where portability, low cost and ease of installation were needed.

The doppler type strap on meter was better suited for many pump efficiency measurements. This unit will not work with completely clear water, but must have a small amount (about 5 percent) of sediment particles, air bubbles or intense, fine scale eddies present in the water. Only one transducer unit is required and it is attached with tape or a strap to the outside of the pipe with a layer of silicone grease between transducer and pipe. An ultrasonic frequency signal is produced by the meter unit which travels through the pipe wall and is directed upstream into the water. There the sound penetrates into the flow and then is reflected back by the particles of air or sediment and is at the same time transported downstream. Due to the well known doppler effect, the frequency of the reflected beam will be higher than the frequency of the transmitted signal. The higher the pipeline velocity, the greater the frequency change. This provides a way to compute the pipeline velocity.

When too few particles are present to give a useful reflected signal most meters display a warning that the signal levels are too low to be reliable. Then air or sediment must be added upstream to the flow if a successful measurement is to be made.

A portable doppler type unit was rented from Polysonics for testing to see if such a meter was suitable for use in a pump efficiency monitor. Measurements of flow in eight wells were made. A summary of the test wells and the results are given in Table 1.

Although signal levels were often marginal in the clean water without air injection, the results were promising enough to justify purchase of a unit.

One portable unit marketed by Bestobel (Model P-12) in Great Britain sells for about $2,000 in this country. A P-12 was acquired and further testing confirmed the conclusions drawn earlier as follows:

1. If the pump is set within 50 feet of the ground level, air injection is not necessary for a good measurement. Entrained air and intense eddies give adequate reflection for the measurement.

2. If 10 diameters or more unobstructed approach distance is not available, the meter will likely give an incorrect flow rate due to the abnormal velocity distribution in the pipe. In this case an in-place field calibration of the unit should be done against some other flow measurement device.

Where air injection is needed, it can be supplied by a small, low cost ($20) 12 volt air compressor and power supply. A small storage tank with pressure switch allows the compressor to run intermittently.

Other flow meters. Many other flow meters are available for permanent installation. Most require modification of the piping system and are thus not readily portable. Venturi meters, orifice plates, propellor meters, etc., belong in the group. Magnetic meters were once large and bulky but now are smaller and lighter. Most are built into special sections of pipe and thus require modification of the pipe system. However, some magnetic meters require only the insertion of a small diameter probe into the pipe and are just as easily installed as a pitot type meter, but are more costly.

Tracer methods. A tracer injected into a flow can be used to measure velocity by measuring the time to move a fixed distance. Thus a velocity
Table 1. Doppler ultrasonic meter tests on wells in Cache Valley.

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<tr>
<th>Well Identification</th>
<th>Signal Strength</th>
<th>Would Air Injection Be Required?</th>
<th>Unobstructed Upstream Distance</th>
<th>Depth to Pump (ft)</th>
</tr>
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<tr>
<td>UWRL Turbine Pump</td>
<td>High</td>
<td>No</td>
<td>&gt; 10 Diameters</td>
<td>10</td>
</tr>
<tr>
<td>Drainage Farm Booster</td>
<td>High</td>
<td>No</td>
<td>~ 5 D.</td>
<td>4</td>
</tr>
<tr>
<td>Crockett Ave., Logan City</td>
<td>Low</td>
<td>Yes</td>
<td>~ 4 D., Unstable</td>
<td>&gt;130</td>
</tr>
<tr>
<td>Smithfield Irr. Co. (150 W. Center)</td>
<td>High</td>
<td>No</td>
<td>&gt; 5 D., Very Stable</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Smithfield Irr. Co. (450 S. 2nd W.)</td>
<td>High</td>
<td>No</td>
<td>&gt; 15 D., Stable</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Lions Lodge Well</td>
<td>Low</td>
<td>Yes</td>
<td>~ 5 D., Unstable</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Smithfield City Well (Ballpark)</td>
<td>Begins High, Later Low</td>
<td>No</td>
<td>Entrained air gives stable signal at first but not good later</td>
<td>Unknown</td>
</tr>
<tr>
<td>Logan City, 7 N. 6 E.</td>
<td>Low</td>
<td>Yes</td>
<td>~ 6 ft, Very Stable</td>
<td>Unknown</td>
</tr>
</tbody>
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measurement becomes a matter of counting elapsed time. Since a counter/timer unit had been developed to measure power input, some experiments with tracers were conducted to see if a low cost tracer/flow meter could be developed.

The concept was tried out first using dye injection in a transparent section of pipe. A TV camera recorded the movement of the cloud past two lines inscribed around the pipe at a known distance apart. Using the built-in frame by frame advance system, the elapsed time was measured. The system was obviously not suitable for installation in a municipal or irrigation piping system, but did give some valuable insights into the design and operation of the tracer injection system.

The next tracer used was common salt water. Simple probes signaled passage of the tracer cloud with a rise in conductivity. A counter gave elapsed time between signals from the probes. However, because of understandable objections to adding salt to drinking water or irrigation water, this method was abandoned.

The last tracer tried was hot water. There usually is no objection to adding a little hot water to the flow, but problems in finding sensors to detect the passage of the warm cloud were formidable. When sensor and circuit development costs became too great, attempts to use a tracer technique for flow rate measurement were abandoned.

**Pumping Lift Measurement**

The pumping lift is the difference in elevations of the total energy line at the inlet and outlet of the pump as illustrated in Figure 1.

Bubbler tube. The pumping lift, \( E_p \), in a pumped well can be most conveniently measured by means of a bubbler tube and a differential pressure gage. A bubbler tube is a small diameter fixed pipe installed in the well so that an end is always below the water surface in the well. The upper end is connected to a pressure gage and a source of air so that a small amount of air can be forced out the lower end a bubble at a time. Pressure, \( P_b \), in the bubbler tube then depends on the depth of the lower end below the water surface. By connecting the bubbler tube to the low side of a differential pressure gage and the delivery line to the high side, the pumping lift is then given by Equation 3 where \( P_L - P_b \) is the reading of the differential pressure gage in psi.

Every water well should have a bubbler tube installed at the time the pump is set in the well, but most wells are not so equipped. Fortunately it usually is possible to add a plastic (Tygon) tube to the well at a later date. This can be done by attaching some small segments of articulated weights (about 1/2 lb is sufficient for Tygon tubing) to the end of 1/4 inch plastic tubing which is then lowered down the annular space between the casing and the delivery line in the well. The end of the tubing should be far enough below the water surface so that the bubbler line is always submerged. Purpose of the segmented weights is to allow it and the tubing to be threaded through the small diameter access hole usually found in the base plate of the motor. Stretching of the Tygon tubing was experimentally found to be non-significant compared to other inaccuracies in the system.

Due to irregularities in the hole alignment, the tubing sometimes becomes stuck between casing and delivery line. When this happens it sometimes helps to turn the pump on and off. This shakes the pump column and often frees the bubbler line so that it will slide on down the hole.

Low cost air supply. Commercial bubbler tube supply units are available.
These consist of a high pressure tank for air storage and a flow controller which releases the air in at a very slow rate. For this project another approach was developed. Air was supplied by a small, inexpensive air compressor for emergency inflation of automobile tires. The compressor delivers air to a small pressure tank and is turned on and off as needed by a pressure controller. Air from the tank is controlled and measured into the bubbler line by a low cost tapered tube flow meter. A flow of 0.5 to 1.0 SCFH (standard cubic feet per hour) is sufficient for the bubbler tube and can be easily supplied by the small compressor for long periods of time. Furthermore, air for injection into the pipeline for the ultrasonic doppler flow meter measurement can be supplied by the same system.

**Input Power Measurements**

Reading the wattmeter manually. Electrical wattmeters measure energy consumption by using a rotating disc in an electrical field. The strength of the field and therefore the rate of rotation of the disc (power) is directly proportional to the product of the applied voltage and the resultant current. The shaft of the disc connects to a set of gears which turn pointers to indicate the energy consumed in kilowatt-hours. To determine the power or rate of energy consumption all that needs to be done is first determine the meter constant \( K_h \) which is generally printed somewhere on the face of the meter and then measure the time required for a revolution of the disc. This is easily done with a stop watch since the disc has a short black stripe on it thus enabling an observer to determine when a revolution has occurred. Units of \( K_h \) are usually watt-hours per disc revolution. To improve the accuracy of measurement, it is best to time the disc for 10 revolutions. Since \( K_h \) are watt-hours per revolution and disc revolution measurement is in seconds, it is necessary to multiply the resulting number by 3600 to find the correct power in watts. An example should help to explain this measurement:

Suppose the meter \( K_h = 46.3 \) and the disc made 10 revolutions in 15 seconds. The power consumption would be

\[
P_{in} = 46.3 \times \frac{10}{15} \times 3600
\]

\[
= 111.12 \text{ watts or } 0.11112 \text{ kilowatts}
\]

This number would then be substituted into Equation 1 to find the pumping system efficiency.

Semi-automatic power measurement. Using a regular wattmeter to determine the instantaneous power requires a measurement of the rate of rotation of the wattmeter disc. The power can then be found by using the \( K_h \) factor printed on the meter face. When automating power measurement it is convenient to count the time for 1 revolution. Then

\[
\text{Watts} = \frac{(3600 \ K_h)}{M}
\]

where

\[ M = \text{sec/rev} \]

To evaluate \( M \) it would be necessary to have a counter which counts seconds during one revolution. As an alternative, since 60 cps is conveniently present, the number of 60 cps cycles which occur during one revolution could be counted. This number will be 60 times \( M \) and the equation

\[
\text{Watts} = \frac{(60)(3600)K_h}{60 M} = 216,000 \frac{K_h}{C}
\]

or

\[
K_W = \frac{216 \ K_h}{C} \quad (6)
\]

where \( C \) is the number of 60 cps cycles in one revolution. Some meter installations have a current transformer in the
circuit. If so, it will produce a multiplying factor on $K_h$. The factor is stamped on the coil and usually is between 2 and 10. For a semi-automatic monitor system, the monitor unit will count and display the factor $C$. The operator need only obtain $K_h$ from the meter face, read the displayed count and substitute into the above equation.

The semi-automatic system to accomplish the power measurement is shown in the schematic diagram of Figure 2. In order to use this system it is necessary that the power company install a switch on the meter. This is a standard accessory and can readily be added to any power meter for about $500. This switch (one type is called a D-52 pulse initiator) will briefly close once for each revolution of the meter disc and thus facilitate the required measurement.

The circuit functions as follows: The D-52 switch sends a + signal to 4098-A through a 4093 SchmidtTrigger NAND gate. The output of 4098-A does two things, 1) toggles the 4027 (through 4098-B) and 2) produces an output (reset) pulse out of 4093 pin 10, if the 4027 $Q$ line is high at the time. If the 4027 $Q$ line is low, no reset pulse will be produced. If a reset pulse is produced, the counter is reset and the display goes to 0. The rising edge of the $Q$ pulse from 4098-B toggles the 4027 whose $Q$ line enables 4093 pin 13 so that the 60 Hz pulses on pin 12 are passed on to the counter. The counter accumulates 60 cps counts until the next closure of D-52 which repeats the above sequence except that with 4027 $Q$ high there will be no 60 Hz pulses to the counter so it just holds the count obtained at the end of the first revolution.

The waveform at various indicated points in the circuit are shown in Figure 3. It will be seen that the display counts during one disc revolution and displays during the next. This affords the operator sufficient time to observe and manually record the count to be entered into the equation. For improved accuracy, if power fluctuates, it is recommended that several sequential readings be recorded and the average taken.
Figure 2. Counter/timer circuit diagram for input power measurement.
Figure 3. Input power measurement counting sequence diagram.
CHAPTER III
LOW COST SEMI-AUTOMATIC MONITOR DEVELOPMENT

The semi-automatic pump efficiency monitor development began with an experimental prototype model which was followed by two improved production models.

Prototype Model

The prototype monitor unit had the following components:

- Power supply to make available 12 v. DC for the compressor and the 5 v. DC for the timer circuits.

- Compressor, air tank and controls to supply air for the bubbler tube and for air injection if the ultrasonic flow meter was used.

- Accutube and differential pressure gage (0-10 inches water) to determine the pump discharge rate.

- Pump lift differential pressure gage to measure pumping lift (0-60 psi).

- Counter-timer and display to measure the number of 60 cps counts during one revolution of meter disc.

- Miscellaneous wiring, switches, tubing, bleed valves, air flow meters and control valves.

- Hand held calculator for efficiency computations.

Most of the components were roughly mounted in a carrying case for convenience of transport. The prototype unit was first built, installed, tested and evaluated for ease and accuracy of operation on one of the pumps at the Utah Water Research Laboratory. Later in the spring of 1980 it was installed on the Kimberly, Idaho, city well No. 1 where it operated intermittently for over two years until it was dismantled and used for parts when the totally automatic unit was developed. Site parameters for the Kimberly No. 1 well were as follows:

- Delivery line I.D. = 8.225 inches.

- Approximate discharge = 800 gpm. Measurement by means of an "Accutube" pitot device and a differential pressure gage or by a Bestobel Ultrasonic Meter.

- Approximate line pressure = 34 psi.

- Vertical distance from pump lift gage to bottom of the existing bubbler tube = 228.3 ft.

- Power meter is equipped with D-52 pulse initiator switch.

- Power meter factor is 57.6 and current transformer factor = 2.

- The delivery pipe has a check valve and a 90° elbow, then a straight piece of pipe about 10 diameters long before the pipe goes underground. The set of operating instructions shown in Table 2 were prepared based on the site parameters and monitor characteristics.

While the monitor unit was set up at UWRL, several persons were invited to
Table 2. Pump efficiency monitor instructions for prototype unit installed at Kimberly City Well No. 1.

1. Turn on master switch "A". Compressor will start and pump air tank up to 30 psi (gage "C") and shut off.

2. Close bypass valve below gage "B". Read gage "B" and record the differential pressure head, $\Delta h_w$ (inches of water) after the gage stabilizes.

3. Turn on bubbler tube air flow gage "D" until indicator shows 1.0 SCFM (ball at red line). The ball will slowly drop as the pressure in the air tank goes down. Thus, small adjustments may be needed until gage "E" stabilizes. Read gage "E" and record pressure $\Delta P$ (psi) after gage stabilizes and reaches its lowest point.

4. Note the 3 digit electronic time display "F" and record the average of at least 5 readings (T).

5. Calculate pump efficiency, $E$, from equations shown below.

6. Record the reading from the pressure gage on the discharge pipe.

7. At end of monitor test: (a) Turn off air flow gages (b) Turn off master switch "A" (c) Open bypass valve beneath gage "B" (d) Turn off and stow calculator

8. Equations for individual calculations:
   (a) Velocity, ft/sec: $V = (1.548) \sqrt{\Delta h_w}$
   (b) Discharge: $Q_{cfs} = 0.369V; Q_{gpm} = 0.369(449)V$
   (c) Pumping head or total lift, ft: $E_p = (2.31)(\Delta P) + 228.3 + V^2/64.4$
   \hspace{2cm} ($V^2/64.4 = 0.35$ ft).
   (d) Power out, (KW): $P_o = (0.0846)(Q$ in cfs$(E_p)$
   (e) Power in, (KW): $P_i = 24883/T$
   (f) Pump efficiency in percent: $E = $ Power out $(100)/$Power in

9. Alternate method to obtain $V$ in ft/sec: Read directly from the Bestobel meter "G" while injecting air into the pump delivery line by turning on air flow gage "H" to 1 SCFH.
use the monitor to determine the pumping system efficiency. Some were engineers, some were shop technicians and some were students. With just a few minutes to study the written instructions but with no other training with the unit, each person was able to successfully complete an efficiency measurement. While such persons who were not familiar with the monitor unit could use it to determine pump efficiency, they probably could not recognize if something was wrong with the unit, and could not cope with malfunctions or diagnose the cause of failures. Trained persons would still be needed to make periodic inspections of the monitor to see that it was in working order.

Since the prototype unit was installed inside a pump house, there was no need to weatherproof it or take special care to guard against freezing conditions in the wintertime.

Table 3 shows some typical efficiency values for the Kimberly City Well No. 1. The data indicate a drop in efficiency in 1982.

Production Models

One production model was a low cost semi-portable unit and the other was a medium cost, portable unit. Both units were carefully packaged in a carrying case for protection from the weather and from vandals and for convenience when transporting them.

Low cost unit. This unit is shown in Figure 4 and has the following components:

- Power supply for the compressor.
- Compressor system to supply air to the bubbler tube.
- "Annubar" and differential pressure gage to measure pump discharge.
- Bubbler tube pressure gage.
- Miscellaneous wiring, switches, tubing, valves and air flow meter.
- Hand-held calculator with stop watch capability for timing the disc and computing the efficiency.

The low cost unit was initially installed on a well belonging to Gary Nebeker located 1/2 mile south and 1/2 mile east of N3000, E4300 near Kimberly. Site parameters are as follows:

- 100 H.P. pump.
- Delivery line I.D. = 8.06 inches.

The line pressure was not measured since the pump delivery is into an open ditch after just 14 ft of pipe. Bubbler tube pressure was measured by pressure gage.

No bubbler tube was in the well, but a plastic bubbler line was successfully installed. Vertical distance from the end of the bubbler tube to the center of the delivery line at the ditch is 451 ft.

The power meter was not equipped with pulse initiator switch so the disc rotation was timed by the calculator/stop switch.

The operating instructions for the unit are given in Table 4 and a typical measurement in Table 5. Approximate production cost of the unit was $2,250 not including development costs. Mass production and purchasing would reduce this somewhat, but manufacturers profit would make the selling price near the above amount.

Medium cost unit. The unit is shown in Figure 5 and has the following components:
Table 3. Pump efficiency data--Kimberly City Well No. 1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Discharge Flow Rate (gpm)</th>
<th>Power (Kw)</th>
<th>Pumping Head (ft)</th>
<th>Pump Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/10</td>
<td>790</td>
<td>67.6</td>
<td>283</td>
<td>62.2</td>
</tr>
<tr>
<td>6/11</td>
<td>803</td>
<td>67.6</td>
<td>285</td>
<td>64.0</td>
</tr>
<tr>
<td>7/30</td>
<td>807</td>
<td>67.4</td>
<td>285</td>
<td>64.3</td>
</tr>
<tr>
<td>1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/11</td>
<td>807</td>
<td>68</td>
<td>283</td>
<td>63.1</td>
</tr>
<tr>
<td>6/19</td>
<td>790</td>
<td>68</td>
<td>284</td>
<td>62.8</td>
</tr>
<tr>
<td>7/16</td>
<td>803</td>
<td>67</td>
<td>286</td>
<td>64.5</td>
</tr>
<tr>
<td>7/24</td>
<td>799</td>
<td>67.4</td>
<td>284</td>
<td>63.2</td>
</tr>
<tr>
<td>7/30</td>
<td>799</td>
<td>67.4</td>
<td>284</td>
<td>63.2</td>
</tr>
<tr>
<td>8/20</td>
<td>798</td>
<td>67.4</td>
<td>284</td>
<td>63.3</td>
</tr>
<tr>
<td>9/10</td>
<td>798</td>
<td>67.2</td>
<td>282</td>
<td>63.0</td>
</tr>
<tr>
<td>9/23</td>
<td>808</td>
<td>67.6</td>
<td>277</td>
<td>63.9</td>
</tr>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/27</td>
<td>726</td>
<td>68.1</td>
<td>285</td>
<td>57.2</td>
</tr>
<tr>
<td>6/11</td>
<td>726</td>
<td>67.8</td>
<td>290</td>
<td>58.6</td>
</tr>
<tr>
<td>7/2</td>
<td>734</td>
<td>67.2</td>
<td>284</td>
<td>58.3</td>
</tr>
<tr>
<td>7/9</td>
<td>734</td>
<td>67.8</td>
<td>281</td>
<td>57.3</td>
</tr>
<tr>
<td>8/6</td>
<td>726</td>
<td>67.4</td>
<td>284</td>
<td>57.7</td>
</tr>
</tbody>
</table>
Figure 4. Low cost monitor unit.
Table 4. Pump efficiency monitor instructions (Gary Nebeker Well).

1. Remove front cover of monitor box. Attach extension cord between the monitor box and the 110 V outlet on bottom of the pump starter box. Turn on master switch "A". Compressor will start and pump air tank up to 40 psi (gage "b") and will shut off.

2. Open both of the small valves on top of the flow sensor in the pump delivery line. These control the flow through the 1/4 inch tubing connecting the monitor box and the flow sensor. Both 1/4 inch lines must be completely full of water. Close the bypass valve connecting the two 1/4 inch tubes where they enter the monitor box.

3. Turn on bubbler tube air flow gage "C" until indicator shows 1.0 SCFH. Record lift pressure, p, from gage "D" in psi after the gage stabilizes and reaches its highest point.

4. Record differential pressure, $\Delta h_w$, from gage "E" in inches of water after the gage stabilizes at its highest reading.

5. Familiarize yourself with the operation of the calculator as a stopwatch. Time the seconds, $T$, required for 10 revolutions of the power meter disc. Take an average of at least 3 readings of $T$ and record it.

6. Calculate the discharge, pumping lift, power output, power input, and the efficiency using the equations below.

7. At the end of the efficiency test:
   (a) Turn off air flow gage "C".
   (b) Close both tubing valves on top of flow sensor on pipeline.
   (c) Open bypass valve between tubing where it enters box.
   (d) Turn off master switch "A".
   (e) Stow calculator.
   (f) Remove extension cord and replace monitor box cover.

   Velocity, $V$, in feet per second $V_{fps} = 1.526 \sqrt{\Delta h_w}$

Equations:

- Discharge, $Q$  
  $Q_{cfs} = 0.541 \sqrt{\Delta h_w}$  
  $Q_{gpm} = 243 \sqrt{\Delta h_w}$

- Pumping Lift, $E_p$  
  $E_p = 451.3 - (2.31)(\Delta P)$

- Power Output, $P_o$  
  $P_o = (0.0846)(Q_{cfs})(E_p)$

- Power Input, $P_i$  
  $P_i = 1,728/T$  
  $T =$ Time in seconds for 10 revolutions of the disc

- Efficiency (%), $E$  
  $E = (P_o/P_i)(100)$
Table 5. Pump efficiency monitor data sheet (Gary Nebeker Well).

<table>
<thead>
<tr>
<th>Date</th>
<th>Bubbler Pressure</th>
<th>Differential Pressure</th>
<th>Time for 10 Revolutions</th>
<th>Flow Rate</th>
<th>Pumping Lift</th>
<th>Power Output</th>
<th>Power Input</th>
<th>Pump Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ΔP psi</td>
<td>Δh_w inches H₂O</td>
<td>Seconds</td>
<td>Q cfs</td>
<td>Ep ft.</td>
<td>P₀ kw</td>
<td>Pᵢ kw</td>
<td>E %</td>
</tr>
<tr>
<td>19 June</td>
<td>13.6</td>
<td>6.9</td>
<td>20.5</td>
<td>1.42</td>
<td>419.9</td>
<td>50.4</td>
<td>84.3</td>
<td>59.8</td>
</tr>
<tr>
<td>16 July</td>
<td>7.1</td>
<td>6.7</td>
<td>20.9</td>
<td>1.40</td>
<td>434.9</td>
<td>51.5</td>
<td>82.7</td>
<td>62.3</td>
</tr>
<tr>
<td>24 July</td>
<td>5.6</td>
<td>6.4</td>
<td>21.0</td>
<td>1.37</td>
<td>438.4</td>
<td>50.8</td>
<td>82.3</td>
<td>61.7</td>
</tr>
<tr>
<td>31 Aug.</td>
<td>13.0</td>
<td>6.9</td>
<td>20.6</td>
<td>1.42</td>
<td>421.3</td>
<td>50.6</td>
<td>83.9</td>
<td>60.3</td>
</tr>
<tr>
<td>10 Sept.</td>
<td>13.5</td>
<td>7.0</td>
<td>20.4</td>
<td>1.43</td>
<td>420.1</td>
<td>50.8</td>
<td>84.7</td>
<td>60.0</td>
</tr>
<tr>
<td>23 Sept.</td>
<td>12.6</td>
<td>6.8</td>
<td>20.3</td>
<td>1.41</td>
<td>422.2</td>
<td>50.4</td>
<td>85.1</td>
<td>59.2</td>
</tr>
</tbody>
</table>
Figure 5. Medium cost monitor unit.
Power supply for compressor and timing circuit.

Compressor system for the bubbler air and injection air for the Ultrasonic flow meter.

Bestobel Ultrasonic flow meter to measure pump discharge.

Pump lift differential pressure gage.

Counter-timer and display to measure the 60 cps counts during a revolution of the disc.

Miscellaneous wiring, switches, tubing, valves and air flow meters.

Hand held calculator to compute efficiency.

The medium cost unit was initially installed on a well belonging to Kevin Stanger located 1/2 mile south of the Kevin Stanger home at N3200, E4000 near Kimberly. Site parameters are as follows:

Delivery line I.D. = 10.5 Inches

Approximate discharge = 900 gpm. Measurement by Ultrasonic flow meter.

Approximate line pressure = 75 psi

From the pump there was 2 1/2 ft of delivery line, then a welded-in check valve, then 1 1/2 ft of pipe, followed by a 45° elbow and then only 3 1/2 ft before the delivery pipe went underground.

No bubbler tube was in the well but a plastic bubbler line was successfully installed. Vertical distance from end of bubbler tube to center of lift gage is 298 ft.

The power meter was equipped with a pulse initiator switch (charges by Idaho Power for this was $516).

The operating instructions for the unit are given in Table 6 and a typical measurement in Table 7. The efficiency is thought to be higher than is likely for the well. This is believed to be due to the extremely short line (2 1/2 ft) available above ground for location of the sensor for the Bestobel Ultrasonic flow meter. The check valve, elbow and short distance means the velocity is not distributed as it should be for a factory calibrated measurement. The meter could give accurate flows if the meter could be calibrated in place, but this was not possible without extra costs. Since the primary purpose of this work was to test the reliability and ease of operation of the unit, no effort was made to check the calibration of the meter in place. This should be done if accurate readings are required.

Cost of the medium unit was about $3,300 to which should be added cost of the pulse initiation switch.

Both production units were packaged in a weatherproof box. Both units had to be drained in the fall to prevent damage to the components by freezing. This is not a problem on an irrigation well, but additional "winterizing" work would be needed to keep the units located outdoors running in the winter. For winter operation, pressure taps must be replaced by a sensor ring such as those marketed by Red Valve Co. and shown in Figure 6. Thus, one sensor ring would be needed at each pressure tap location. The Nebeker well would need two (for flow measurement). The "flow" differential pressure gage would have to be replaced by two identical pressure gages of a type that would measure the pressure without much movement of fluid in the lines. The fluid in the lines between sensor rings and transducers would be anti-freeze. Stanger's well would also require two sensor rings on the lift differential pressure gage. The ultrasonic meter would need no winterizing. Costs per sensor ring would be about $300 or $600 for each unit.
Table 6. Pump efficiency monitor instructions (Kevin Stanger Well).

1. Remove front cover of monitor box. Attach extension cord between the monitor box and the 110 Volt outlet on bottom of the pump starter box. Turn on master switch "A". Compressor will start and pump air tank up to 100 psi (gage "B") and will shut off.

2. Open both of the small valves on top of the pump delivery line. These control the flow through the 1/4 inch tubing connecting the monitor box and the delivery pipe.

3. Turn on bubbler tube air flow gage "C" until indicator shows 0.5 SCFH. Record lift pressure, p, from gage "D" after the gage stabilizes and reaches its lowest point.

4. Turn on air injection flow gage "C" until indicator shows 2.0 SCFH. Turn on Bestobel flow meter "E" by pushing "On" button. After a short time the signal strength meter should read greater than 6 and the velocity meter will reach a maximum. Record the velocity, V, on data sheet. The meter will automatically turn off after 1 minute. Be sure the "Fluid Calibrate" dial is set at 0.5 and the "Noise Cancel" dial is full clockwise. Because of electrical interference from the compressor unit, read the flow meter only when the air compressor is not running.

5. Note the 3 digit electronic timer display "F". Record the average of at least 5 readings of T.

6. Calculate the discharge, pumping lift, power output, power input and the efficiency using the equations below.

7. At the end of the efficiency test:
   (a) Turn off air flow gages "C" and "G".
   (b) Close both tubing valves on top of pump delivery line.
   (c) Turn off master switch "A".
   (d) Turn off and stow calculator.
   (e) Remove extension cord and replace monitor box cover.

Velocity, V, in feet per second from Bestobel flow meter

Equations:

(a) Discharge, Q
\[ Q_{cfs} = 0.601V \quad Q_{gpm} = 269.8V \]

(b) Pumping Lift, E_p
\[ E_p = 298.2 + (2.31)(p) \]

(c) Power Output, P_o
\[ P_o = (0.0846)(Q_{cfs})(Ep) \]

(d) Power Input, P_i
\[ P_i = \frac{82,944}{T} \quad T= \text{Number of 60 cps counts in one revolution of the disc} \]

(e) Efficiency (%), E
\[ E = \left(\frac{P_o}{P_i}\right)(100) \]
Table 7. Pump efficiency monitor data sheet (Kevin Stanger Well).

<table>
<thead>
<tr>
<th>Date</th>
<th>Lift Pressure</th>
<th>Flow Velocity</th>
<th>Timer Reading</th>
<th>Flow Rate</th>
<th>Pumping Lift</th>
<th>Power Output</th>
<th>Power Input</th>
<th>Pump Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 June</td>
<td>71.3 psi</td>
<td>3.6 fps</td>
<td>822</td>
<td>2.16 cfs</td>
<td>462.9 ft.</td>
<td>84.6 kw</td>
<td>100.9 kw</td>
<td>83.8 %</td>
</tr>
</tbody>
</table>
Both units operated successfully for two summers at their initial installations. They performed consistently and reliably except for the flow measurement on the Stanger well as already discussed.

Both units could be operated by inexperienced people if they would take time to study and follow the given directions.

Figure 6. Sensor ring for winterized operation.
CHAPTER IV
FULLY AUTOMATIC MONITOR SYSTEM DEVELOPMENT

Concept and Capability

The fully automatic monitor system was developed under an extension of the original contract in response to the perceived need for a system that would not require an operator to do any part of the measurement, computations, or recording of the data. The objective was to produce a compact, semi-portable system which could initiate a measurement of pump efficiency at any pre-selectable time, measure and store all the necessary parameters, make the needed computations, and then both display and print the relevant information.

Initially the plans were to convert an available calculator or computer device to perform the tasks. Soon it became apparent that a unique, special purpose computer system could be developed just as readily which would have the added advantage of greater flexibility and reliability. The computer system chosen is based on the 8 bit Z-80A microprocessor.

Description of the Fully Automatic System

The fully automatic system was packaged in two cases as shown in Figure 7 which contain the following components:

- **Auxiliary equipment case.**
  - Power supplies for compressor, transducers, and solenoid valves.
  - Compressor, air tank, and air flow controls to supply air for the bubbler tube.
  - Pump lift differential pressure transducer to measure pumping lift (0-100 PSID).
  - Accutube and differential pressure transducer to measure pump discharge rate (0-20 inches water).
  - Solenoid valves for protecting the flow transducers between measurements, bleeding accumulated air from the lines, and determining the zero flow condition.
  - Miscellaneous wiring, connectors, switches, bleed valves, etc.

- **Computer case.**
  - Power supplies for computer, printer, clock, and other circuits and controls.
  - Computer to control operations, make calculations, and display and print the results.
  - Display module for Efficiency, Power In, Lift, and Flow.
  - Paper tape printer with choice of continuous or once a day readings.
  - Real time clock with initialization (setting) capability.
  - EPROM for programmable memory.
  - ROM for storing site data through switch selectable inputs.
  - Umbilical connection to auxiliary case.
  - The operations done by the monitor unit make the necessary measurements and
then evaluate the pumping system efficiency using the following equation:

\[
\text{Efficiency (\%)} = \frac{0.0846 \cdot V \cdot A_{L} \cdot (H + \frac{V^2}{64.4} + 2.31 \Delta P)}{\text{meter factor} \div \text{time for 1 disk rev.}}
\]

where \( V = 1.52 \Delta h_w \), and \( h_w \) is the differential pressure head in inches of water.

The pitot tube device used to determine the flow rate requires the measurement of a small (about 10 inches of water) differential pressure in a pipe with a high line pressure (usually > 50 psi). The small differential pressure to be measured requires a sensitive transducer which is vulnerable to damage should a larger differential occur for any reason. Furthermore, air bubbles may accumulate in the tubing and this requires bleeding the air bubbles from the system. Finally, some electrical drift occurs in all transducers if given enough time and this requires some means of taking a "zero" reading as a reference for the measurement.

The pumping lift is usually large so a much less sensitive transducer is used. Only an occasional manual air bleed is needed to keep this transducer in operating condition.

**Sequence of Events During Monitor Operation**

The operation of the monitor system can best be described by listing the sequence of events which occur during a set of measurements. It is assumed that the monitor unit has been installed at a well site, that the real time clock has been set to local time, and the site constants have been loaded in the
computer memory by following the instructions in Appendix A.

1. Begin a measurement upon a signal from a switch or from the real time clock.

2. Measure 10 revolutions of the power meter disk and compute and store the power input, $\text{P}_{\text{IN}}$.

3. Measure and store the lift pressure, $\Delta P$.

4. Operate solenoid valves to protect the flow transducer between readings, to bleed air from the lines prior to a reading, and to make and record a "zero" reading of the transducer.

5. Measure the velocity differential pressure head, $\Delta h_w$, by reading the flow transducer and subtracting the zero reading. Then compute and store the velocity, $V$, in Equation 5.

6. Compute and store the pumping lift, $E_p$, in Equation 3.

7. Compute and store the flow rate, $Q$, in Equation 4.

8. Compute and store the efficiency, $E$, in Equation 7.

9. Display the Efficiency, Power In, Lift, and Flow Rate.

10. Print the well number, day, date, time, Efficiency, Power In, Lift, and Flow Rate.

11. Repeat the sequence above two more times to complete a set of three measurements.

12. Wait for the signal to begin the next series of measurements (2 min to 24 hr as selected by setting the switch to "Continuous" or "24 hr").

Since the monitor unit is completely automatic in its operation, no instructions are needed for operation once it has been installed and set up by a qualified person. The experimental unit was not installed in a weatherproof box, however, and it must be given suitable protection in a shelter and kept above freezing temperature.

The automatic monitor unit was installed initially inside the pump house of the Kimberly City well where it operated successfully for two periods of several months each. Figure 8 shows typical data from the printer. Each time service was ended by failure of the same integrated circuit chip at the time of a power outage. Apparently a transient power surge damaged the chip. Protection of the unit with a constant voltage transformer or surge arrester is recommended.

Once a week the air that accumulates in the line pressure transducer tubing should be bled out by slowly opening the bleed valve for a few seconds. Now and then the paper tape in the printer must be replenished and the printed tape record removed. Normally no other routine maintenance is needed.

A more detailed description of the monitor unit and its electrical circuits is given in Appendix A. Instruction for initial installation at a site, inputting the site parameters, setting the real-time clock, and starting up the unit are also given in Appendix A. The computer program that runs the unit is listed in Appendix B.
Figure 8. Typical printer tape.
CHAPTER V

SUMMARY

The Utah Water Research Laboratory of Utah State University has developed, tested, and evaluated four low-cost, pump efficiency monitors. The units are packaged for convenience in a carrying case(s) and can be installed permanently or used as portable units. The prototype and two of the simpler units require the operator to read some gages and then use a hand-held calculator to make some simple calculations to determine efficiency. One model uses a pitot tube device and the other an ultrasonic meter to measure flow rate. The final model is totally automatic in its operation. A timer turns the unit on at a programmed time and the unit itself makes all the measurements and calculations, displays the results, and also prints a permanent record. The unit can also be set for continuous operation. Costs of the units, not including development costs, are between $2,250 and $5,500 depending on the sophistication.
APPENDIX A

COMPUTING ELECTRONICS FOR THE AUTOMATIC
PUMP EFFICIENCY MONITOR

This appendix describes the computing electronics for the automatic pump efficiency monitor. The accumulation of data from the velocity, pressure and kWh meter-timer peripheral transducers is accomplished via this unit and the computation of the efficiency of the pumping system is done using the following equation:

\[
\text{EFFICIENCY (\%)} = \frac{P(\text{OUT})}{P(\text{IN})} \times 100 = 0.0846 \frac{V_A}{H} \left( H + \frac{V^2}{64.4} + 2.31 \Delta P \right) (100)
\]

where

- \( V \) = velocity of water in pipe (feet/sec) = 1.548 \( \sqrt{\Delta h_w} \)
- \( \Delta h_w \) = velocity differential head (inches of water)
- \( A_L \) = cross-sectional area of pipe (square feet)
- \( H \) as indicated in Figure A-1, vertical distance from center of lift gage to the end of the bubbler tube (feet)
- \( P_L \) = line pressure (pounds per square inch, psi)
- \( P_B \) = bubbler pressure (psi)
- \( \Delta P = P_L - P_B \) (psi) = lift pressure differential (psi)

The computer system is based on an 8-bit microprocessor, the Z-80A, which was chosen for its availability and copious documentation, ease of operation for the job specification, and the experience with the device.

Because plenty of power was available at the point of use, it was not necessary to base the electronics around a low-power CMOS microprocessor, suitable for battery operation and thus a standard Z-80A operating at 5 volts, with a 2.4576 MHz crystal clock was used.

The electronics accompanying the microprocessor, as found on the main board, and controlled by and/or supplying data to the Z-80A can be divided into the following main areas:

1. Reset and clock
2. Address/data/control bus buffering
3. Input/output, memory address decoding
4. CTC counter/timer circuits
5. PIO input/output circuits
6. Analog-to-digital conversion
7. RAM/ROM memory devices
Figure A-1. Pump lift diagram.
8. Switched ROM devices
9. 7-segment display
10. RTC real time clock
11. Printer output
12. Compressor unit and secondary electronics

The above areas will be elaborated upon with reference to specific circuitry and basic properties that describe each section with respect to the others. The following overall system diagram, Figure A-2, serves to tie in each of the above sections to form the total computer system.

1. **RESET and Clock**

(a) The **RESET** function is a most necessary control in that once activated it stops the microprocessor's execution of instructions and loads the program counter within the Z-80A with 0000HEX, i.e., the lowest memory address. The program is written into an **EPROM** with a starting address of 0000HEX. The application of the **RESET** signal will interrupt the current sequence of instructions and force the program to be initialized, commencing at 0000HEX. The **RESET** (the condition is logic zero) is generated by power-on as well as by push-button momentary contact manual operation. The signal is also fed to the counter/timer circuits.

Upon power-on, the capacitor (47 microfarads in Figure A-3) is initially discharged and a logic 0 will appear on the **RESET** output for a fraction of a second. Once power is on a **RESET** can be obtained by the push-button momentary contact switch being depressed. The processor remains in the **RESET** state as long as the switch is depressed.

(b) The Z-80A requires a single phase clock only and can be run up to 4 MHz. To provide convenient divisions for the CTC timing sequences a 2.4576 MHz clock has been used as shown in Figure A-4 (note that 2.4576/256 = 9600 Hz, 9600/96 = 100 Hz, i.e., 100 pulses per second or a resolution of 1/100th of a second). For consistent execution time and for more precise timing for the CTC, a crystal controlled circuit is used.

The 330 ohm pull-up resistor satisfies the AC and DC clock signal requirements but a separate inverter gate section is used to drive the pull-up.

2. **Address/Data/Control Bus Buffering**

The Z-80A should drive only one TTL load for each output pin and thus it becomes necessary for buffering to be used on all lines that connect to other circuitry; indeed, even a logic probe applied to an unbuffered line may cause fatal results as far as the microprocessor is concerned. Many lines drive parallel devices and buffering provides extra drive. The 74367 non-inverting tristate bus driver is capable of sinking 48 MA and can accommodate any combination of TTL, LSTTL or memory connections.

(a) **Address Bus:**

The 16-bit wide address bus in Figure A-5 is uni-directional and the tristate function of the 74367 is controlled by the **BUSAK** signal which is inverted before application to the driver's control inputs. In a non-DMA application, as in this case, the **BUSAK** is high and the 74367 passes all outputs from the Z-80A. If a DMA request was to be acknowledged by the Z-80A then **BUSAK** would go low, the 74367's placing their outputs in a high impedance mode allowing the address bus to be used by another processor for example.

(b) **Data Bus:**

The reason for buffering the 8-bit wide data bus is the same as for the
Figure A-2. Overall computing system diagram.
Signal diode discharges capacitor quickly upon power-off.

**Figure A-3.** Reset circuit diagram.

**Figure A-4.** Clock circuit.
Figure A-5. Address bus.
address bus, but in this case we wish to make the data bus bidirectional in that data flow is channeled from associated circuits to the microprocessor and vice-versa.

By using the 74367's in opposite pairs we can accomplish the bidirectionality along with the RD read line from the processor. Recall that the tristate nature of the bus drivers enables us to effectively turn the outputs from a normal passing mode to a high impedance mode and the RD line can control this function as diagrammed in Figure A-6.

Note that in a write operation, RD is high which places the control inputs on the top two devices in a low state, allowing the data on the Z-80A data pins to be passed out onto the data bus. The lower two devices (inputs/outputs configured opposite to the other 74367's) have a high logic state present on their control pins which places their outputs in the high impedance state. The read operation is facilitated with the processor putting its RD line low and the top two 74367's go into the high impedance state, the lower two passing data from the data bus to the processor.

(c) Control Bus:

The control signals co-ordinate peripherals and channel data and addresses at the proper times, both into and out of the Z-80A. The control bus is buffered using 7414 HEX Schmitt triggers and buffering is supplied for the following signals:

BUSAK, RD, WR, MI, IORQ, MEMRQ

Unused input signals to the Z-80A are tied high. These include: WAIT, INT, NMI, BUSRQ. Interrupts are not supported in this system, and the HALT and RFSH lines are not used. Thus, the Z-80A is configured such that it is embedded one level using buffering on the address, data, and control busses as in Figure A-7.

3. Input/Output, Memory Address Decoding

By means of the circuit of Figure A-8 the Z-80A can directly address 65,536 (64K) individual bytes (8-bits) of program memory and 256 individual input and output ports. In this system there are available 2048 bytes of EPROM and 1024 bytes of RAM, as well as areas used in a memory mapped configuration. The CTC's and PIO's are used in an I/O environment. Both memory and I/O device addresses need to be decoded to ensure uniqueness in device selection when the address bus has placed on it a valid address by the processor.

74LS138 decoder/multiplexers are used in the 3-to-8 line decoder mode.

The 7-segment LED's and switched ROMs are decoded on 256 byte boundaries. One of the memory mapped signals is used to strobe the A/D's as shown on the diagram.

4. CTC Counter/Timer Circuits

There are two CTC's available one being used as an event timer for the revolution of the kwh meter disk. Eight revolutions of the meter disk are counted by external hardware and the state of a PIO input is flipped each time eight are counted; the time between successive high states gives the elapsed time for eight revolutions which is divided down in the program so that an average value of the power usage can be calculated. Three channels of the available four on the CTC are used to accomplished this event timing and are configured as shown in (Figure A-9.

5. PIO Input/Output Circuits

The PIO circuit is an interface device with 16 I/O pins, divided into two 8-bit I/O ports as shown in Figure A-10. Each I/O port has two associated control lines and each port may be specified separately as an input port, output port or control port.
Figure A-6. Data bus.
Figure A-7. Buffering of address, data, and control busses.
Figure A-8. Memory address decoding.
2.4576 MHZ Clock

Channel 0
Prescaler = 256
Down Counter = 96
\[
\frac{2.4576 \times 10^6}{256} = 9600
\]
\[
\frac{9600}{96} = 100
\]

Channel 1
Down Counter = 100
Counts \(\frac{1}{100}\) ths of a Second

Channel 2
Down Counter = 100
Counts Seconds

Read this channel - take number away from 100 to get number of \(\frac{1}{100}\) ths a second elapsed.

Read this channel - take number away from 100 to get number of seconds elapsed.

Figure A-9. Counter/timer circuits.
Figure A-10. Input/output circuits.
Figure A-10. Continued.
When used as a control port, each of the 8 pins may be individually assigned as an input or output. Furthermore, port "A" may be used as a bi-directional port. While not used in this implementation, the PIO is capable of providing significant interrupt handling capability making the circuit a powerful parallel interface device.

For ease of use, the PIO's in this system have been configured in the control mode (Mode 3). The control signals are not used in this mode and every port pin is defined as either input or output which is easily accomplished in PIO initialization.

6. Analog-to-Digital Conversion

Three ADC0804LCN A/D's have been provided as shown in Figure A-11, two being used in this system; one A/D is used to convert the voltage produced by the bubbler tube pressure transducer and the other converts the voltage from the accutube velocity measuring device via a pressure transducer. The A/D's are used in the free-running mode and strobed by one of the memory mapped outputs.

7. RAM/ROM-Memory Devices

As noted in Figure A-12, both volatile (RAM) and non-volatile (EPROM, ROM) memory is provided, and the program itself is contained in an EPROM capable of storing 2048 bytes. It is decoded to reside in the first 2K of memory, locations 0000HEX - 07FFHEX. The program is listed in Appendix B.

The RAM is used for stack area and temporary storage; 1K is available in hardware but memory space has been left for an extra 1K of RAM. It is mapped in the 2K following the EPROM area, 0800HEX - 0FFFH (0800HEX - 0BFFHEX in hardware).

8. Switched ROM Devices

Many of the variables contained in the efficiency equation are peculiar to the physical location of the pumping system and thus need to be altered according to the site. Adapting the EPROM to suit each location would be tedious and thus 8 x 8-bit switched ROMs in the form of 8 dual-in-line switches have been provided as in Figure A-13. Values of relevant site variables can be initially set up on the switches and the program reads these as actual memory locations as if each 8-bit variable was indeed a memory location in ROM for example. A change in site requires only a change in the switch settings, making EPROM alteration unnecessary. The switches also serve the dual purpose of setting up the RTC upon initialization of this timing device.

The switched ROMs are decoded according to the scheme discussed in the memory decoding section. The 74C240 inverting output octal buffer and line driver with tristate output devices are so designed to drive bus-oriented systems. By strobing the G inputs high, the outputs go into the high impedance state. With the DIL switch in the open position the input to the 74C240 is high and upon inversion places a low on the data bus for the bus line corresponding to the particular switch. By closing the switch, the current is drawn through the 22K resistor to ground and the 74C240 input goes low, and again, upon inversion, the data bus line receives a high.

As noted previously, the switches allow initialization data to be input to the real time clock. The RTC must be set up to the actual time of initialization so that events can be related to the real time as it progresses. By setting one bit aside as a flag bit, it is possible to write this information to the RTC via the DIL switches and then after placing the flag switch in the reset mode the normal site switch data can be set on the switches ready for standard operation (see Figures A-14 and A-15).
Figure 11. Analog to digital conversion circuits.
Figure A-12. RAM/ROM memory devices.
Figure A-12. Continued.
Figure A-13. Switched ROM devices.
Figure A-14. Real time clock variable map.
Figure A-15. Normal location variable map.
9. 7-Segment Display

As noted in the decoding section. The LED display is also memory mapped.

The 4511 BCD-to-7-segment latch/decoder/driver is the integrated circuit used to drive the 7-segment displays (HP-5082-7740) directly. The 4 low order bits of the data bus are used to provide data to the 4511's which are enabled under program control (see Figure A-16).

10. RTC—Real Time Clock

The real time clock is available to give a record of the events with respect to time; the clock can give readings resolved to one second. The format is as follows:

YY MM DD
YEAR MONTH DAY OF MONTH

W HH MM SS
WEEK-DAY HOUR MINUTE SECOND

l = January etc, 0 = Sunday, l = Monday etc.

The set-up is accomplished as explained earlier in the switched ROM section; the PIO interface enables data transfer to and from the RTC. Pull-up resistors of 10K ohms are connected to the data, address and control pins of the clock chip.

11. Printer

The ALPHACOM Sprinter 20 (20 columns wide) is used to provide a more permanent copy of the readings and a full report can be generated on a once per day basis or on demand. The lines from the accutube flow meter are bled prior to the printed output and the accutube pressure transducer is zeroed so that errors are kept to a minimum. Once an error voltage on the accutube pressure transducer is recorded in memory it is used to adjust the subsequent velocity readings until another print/zero transducer reading is requested. A switch on the processor unit is used to select once/day readings or a demand reading. If the switch is left in the continuous setting the printout sequence will occur repetitively, whereas with the once/day setting this task is performed at a particular hour each day. The program is written so that a print/zero sequence is only performed if the pump has been operating at least 5 minutes so that any transients have had some time to settle down.

The print-out sequence is made up of three sets of bleed, zero, and normal operations (i.e., accutube pressure is across velocity pressure transducer) with velocity data being taken at the end of the zero and normal operating times. A print-out is generated for each of the three sets, the complete operation taking approximately 20 minutes. The system is left in the normal operating mode with the data being displayed on the LED's but not printed. The most recent zero reading is used in subsequent calculations.

The printer receives data and control signals via a PIO interface device. The report includes the following:

Example:

SITE#X XX XX XXX XX SITE#1 MO 17 JAN 83
TIME XX:XX:XX TIME 13:39:36
EFFICIENCY (%) XX.X EFFICIENCY (%) 51.5
POWER IN (KW) XX.X POWER IN (KW) 69.6
LIFT (FEET) XXX LIFT (FEET) 285
FLOW (CFS) X.XX FLOW (CFS) 1.49

An example depicting initialization is necessary. The RTC is first set up for an appropriate time; this time is chosen so that upon momentary depression of the
Figure A-16. Display circuit.
RESET button the time as set up on the DIL switches will be loaded into the RTC at that very instant. An example time is: Monday the 17th of January, 1983 and it's 39 minutes past 1 in the afternoon (i.e., 1339 hours).

YEARS TENS = 8 = 1000 LEAST
YEARS UNITS = 3 = 0011 SIGNIFICANT
MONTHS TENS = 0 = 0000 AT
MONTHS UNITS = 1 = 0001 RIGHT
DAYS TENS = 1 = 0001* 
DAYS UNITS = 7 = 0111
WEEKDAY = 1 = 0001
HOURS TENS = 1 = 1101*
HOURS UNITS = 3 = 0011
MINUTES TENS = 3 = 0011
MINUTES UNITS = 9 = 1001
FLAG BIT SET = 1XXX X=DON'T CARES

*The third L.S.B. set on days tens would signify 29 days in February while a reset bit means 28 days. Thus a leap year would have days tens as 0101. Likewise with the hours tens; the third L.S.B. set means that we are using a 24 hour format, and reset 12 hour format. A set fourth bit in hours tens signifies p.m. and reset a.m.

Using the same time group map as was given in the switched ROM section and repeated again below we can set up the initialization time for the RTC as in Figure A-18.

Once the RESET button has been momentarily depressed. The real time has been loaded in for RTC initialization, and it is now possible to set up the switches to hold the site variables. We can choose some appropriate site variables:

LIFT PRESSURE TRANSDUCER FULL SCALE (PSI) = 100 = 01100100
DISTANCE H (IN TENTHS OF FEET) = 2325 = 100100010101
KH KWH METER FACTOR (IN TENTHS) = 1152 = 10010000000
AREA OF PIPE (IN THOUSANDTHS OF SQ. FEET) = 369 = 00101110001

TIME OF DAY TO PRINT/ZERO (24 HR. FORMAT) = 13 = 01101
VELOCITY PRESS.TRANS.F.S.(HUNDREDTHS OF INCH) = 2000 = 01111010000
SITE IDENTIFICATION NUMBER = 1 = 001
FLAG BIT MUST BE RESET = 0 = 0

Load onto switches using Figure A-19.

The above memory mapped locations will be treated as site variables because the flag bit (bottom right hand corner) is not set. It is a good idea to reset this bit a few seconds after depressing the RESET button momentarily when setting up the RTC initialization data, and then set up the switches for the site variables. This ensures that the switches will not be read as RTC data when the program flow loops back to test this bit. Once the site variables have been loaded with the flag bit previously reset then the complete initialization task is finished.

12. Compressor Unit

The air compressor unit is powered by a separate power supply (Figure A-20) and is controlled by a pressure switch mounted on the air tank. As long as the power is on, this system will maintain the pressure set by the pressure switch (approximately 45 psi maximum). This air pressure is used to feed the bubbler tank to provide data on the effective lift over which the pump operates.

13. Data Gathering and Control Circuits

The data gathering and control electronics consist of control circuits to establish the various measurement conditions and transducers to convert these conditions to electronic signals. The circuitry required to accomplish these measurements is shown in Figure A-21. The solenoid valves are connected as shown in Figure A-22.
Figure A-17. Real time clock circuit.
<table>
<thead>
<tr>
<th>Left</th>
<th>2300H</th>
<th>2200H</th>
<th>2100H</th>
<th>2000H</th>
<th>1FOOH</th>
<th>1EOOH</th>
<th>1DOOH</th>
<th>1COOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>D</td>
<td>W</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>A</td>
<td>U</td>
<td>E</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>K</td>
<td>U</td>
<td>U</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>I</td>
<td>T</td>
<td>A</td>
<td>R</td>
<td>R</td>
<td>N</td>
<td>U</td>
<td>T</td>
</tr>
<tr>
<td>E</td>
<td>N</td>
<td>S</td>
<td>S</td>
<td>T</td>
<td>E</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>S</td>
<td>Y</td>
<td>N</td>
<td>T</td>
<td>E</td>
<td>T</td>
<td></td>
<td>FLAG</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIT</td>
</tr>
</tbody>
</table>

- high for 29 days in month 2
- low for 28 days in month 2
- high for 24 hour format
- low for 12 hour format
- high for PM, low for AM
- high for RU
- low for standard

Figure A-18a. RTC map for switched ROMS.
Figure A-18b. Example switch settings for RTC.

Figure A-19. Example switch settings for site variables in the switched ROMS.
Figure A-20. Power supply for compressor unit.
Figure A-21. Diagram of solenoid valves and relay controls.
Figure A-22. Compressor unit connector, solenoid, relay, and transducer connections.
The solenoids operate in pairs with 1 and 4, 2 and 3, 5 and 6 tied together. As noted in Figure A-21, solenoid valves 2, 5, and 6 are normally open and 1, 3, and 4 are normally closed. The function of each pair of valves is described below:

<table>
<thead>
<tr>
<th>Valve Numbers</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 4</td>
<td>Air bleed to purge the system</td>
</tr>
<tr>
<td>2 and 3</td>
<td>Establish conditions to obtain a zero reading</td>
</tr>
<tr>
<td>5 and 6</td>
<td>Protection of the sensitive pressure transducer</td>
</tr>
</tbody>
</table>

The operation of these is normally controlled by the computer program. The manual controls for initial setup should be used with caution. The protection solenoids (5 and 6) should always be actuated (by pressing the white button) before actuating the bleed valves (pressing the small red button). The zero solenoids (black button) would be actuated whenever a zero reading is desired. The program controls the valves as shown in the timing diagram (Figure A-23).

A readout cycle, initiated by the computer program, begins by closing the protection solenoid valves. Two seconds later the air bleed valves are opened and remain open for approximately 17 seconds. At the end of the air bleed period solenoid valves 1, 4, 5, and 6 are all de-energized and valves 2 and 3 are energized. Solenoid valve 3, when energized, provides a shunt path around the transducer so that no differential pressure can exist across the transducer. Solenoid valve 2, when energized, closes off any flow so that the zero reading is not affected by any dynamic water movements. This zero reading is taken just prior to the data reading so that any drifts due to temperature or supply voltage can be subtracted out of the data reading.

The control signals from the computer are passed through "or" gates which permit manual operation of each pair of solenoid valves as shown in Figure A-22.

Because of the large range of the "line pressure" transducer and the resulting low volts/psi output, it is not necessary to zero this unit.

The outputs from the two transducers are fed back to the computer unit where they are smoothed by the circuit shown in Figure A-24 and then used in the final efficiency calculation.
Figure A-23. Solenoid valve timing diagram.
Figure A-24. Smoothing circuitry for (a) velocity and (b) line pressure.
Appendix B

Program Listing for the Automatic Pump Efficiency Monitor as Stored EPROM

Program computes the efficiency of an irrigation pumping system. The equation used is as follows:

\[
\text{Efficiency (in \%)} = \left( \frac{\text{Power Out}}{\text{Power In}} \right) \times 100
\]

\[
= 0.1346 \cdot V \cdot A \cdot \frac{V^2}{2} + A \cdot H \cdot \left( \Delta P \times \frac{100}{1} \right)
\]

Where

- \(V\) = Velocity of water in pipe (feet/sec)
- \(A\) = Cross-sectional area of pipe (sq. feet)
- \(H\) = Distance from pipe axis to bottom of bubbler tube (feet)
- \(\Delta P\) = Pressure difference between line press. and bubbler pressuro (lbs./sq. inch)

The meter factor and disk revolution information relate to the kilowatt-hour meter which is used as a measure of the electrical power being put into the system.

Program listing for the automatic pump efficiency monitor as stored EPROM:

```
 веществ

.780
.PHASE 0

EQUATE FOR THE PROGRAM

KTIM EQU 082AH
TEMP1 EQU 082CH
POWIN EQU 082EH
DELTAP EQU 0830H
PVEL EQU 0832H
LIFTT EQU 0836H
PVELD EQU 0838H
RAMPMT EQU 083CH
DEN EQU 0848H
NUM EQU 084AH
FLOWW EQU 084CH
VELZER EQU 084EH
PRIFLG EQU 084FH
KHFAEM EQU 2100H
KHFACL EQU 2000H
PRESSR EQU 2300H
HIGHT1 EQU 2100H
HIGHT2 EQU 2200H
VEL EQU 1000H
VELM EQU 1000H
PIPFAM EQU 1000H
PIPFAL EQU 1000H
PRITIM EQU 1000H

63
```
**The Program Commences With a Zeroing of the Initial 256 Bytes of RAM and Also the 12 LED Displays.**

```
LD A, 0 ; Zero Accumulator
LD HL, 0800H ; RAM Start - Starting Address for Fill
LD B, 0 ; Fill 256 Bytes with Zeros
FILL:
LD (HL), A ; Store Byte
INC HL ; Increment Pointer
DJNZ FILL ; Continue if B Not Zero
LD B, 0 ; Zero B Register
LD HL, 1000H ; Enter LED Starting Address
NULL:
LD (HL), B ; Zero LED
INC H ; Point to Next LED Address
LD A, ICH ; Have We Zeroed All LEDs?
CP H
JP N2, NULL ; No, So Go Back
LD A, 0 ; Zero Accumulator
LD (PRIFLO), A ; Set Print Flag for Initiation

******************************************************************
* Set the Stack Pointer and Set Up the Counter Timer CCT*
* As Well As the Parallel Input/Output Circuits.*
******************************************************************

LD SP, 0829H ; Set Stack Pointer to Yield 42 Bytes of Stack
LD A, OCFH ; Set Up PIO1 Channel A With All Inputs,
OUT (OCFH), A ; This PIO Receives an Input From The
LD A, OFFH ; Pressure (Delta P) Analog To Digital
OUT (OAH), A ; Converter.

LD A, OCFH ; Set Up PIO1 Channel B: Bits 0 and 1 Are Inputs,
OUT (OBH), A ; 0=Kuh Meter Switch, 1=Zero/Print Flag, Bits 2
LD A, 3 ; To 7 Are Outputs With 2=*56* Solenoid, 3=*14*;
OUT (OBH), A ; Solenoid, 4,5,6=RTC Control, 7=*23* Solenoid,

LD A, OCFH ; Set Up PIO2 Channel B For All Inputs
OUT (OFH), A ; This PIO Is Used for the Velocity A/D
LD A, OFFH
OUT (OFH), A

LD A, OCFH ; Set Up PIO3 Channel A For All Outputs,
OUT (12H), A ; Bits 0 to 6 Are Printer Data and Bit 7 Is
LD A, 0 ; The Data Stroke.
OUT (12H), A
```

64
**THE MAIN PROGRAM INVOLVES A SERIES OF SUB-Routine CALLS.**

**SET UP REAL TIME CLOCK IF FLAGGED**

**WAIT FOR KWH METER TO GO LOW**

**READ POWER-IN INFORMATION IN**

**OBTAIN DELTA P INFORMATION**

**MEASURE VELOCITY OF WATER**

**CALCULATE LIFT**

**CALCULATE FLOW USING VELOCITY AND AREA**

**DISPLAY EFFICIENCY, POWER IN, LIFT, FLOW ON LEDS**

**DO WE WISH TO ZERO/PRINT?**

**GO AROUND AGAIN**

**LOAD OUTER LOOP FOR 100 SECOND TIME-OUT**

**DECREMENT OUTER LOOP**

**LOAD INNER LOOP**

**DECREMENT INNER LOOP**

**IS KWH SWITCH HIGH?**

**TEST BIT 0 = KWH SWITCH INPUT**

**IT'S HIGH, SO SERVICE**
COUNT CLEAR NEW COUNT RESULT

IF CLEAR MSB NOT ZERO CAPTURE COUNT AS NEW COUNT

IF CLEAR MSB ZERO CLEAR ACCUMULATOR AND FILL MSB

IF COUNT NOT ZERO INCREASE COUNT

IF COUNT ZERO STOP AND RECORD RESULT

STORE COUNT AS MSB OF RESULT

STORE COUNT AS LSB OF RESULT

MULTIPLY IN D,E,H,L REGISTERS

DIVIDE IN D,E,H,L REGISTERS

STORE RESULT IN RAM = POWER IN KWH READING
THE FOLLOWING ROUTINE READS THE PRESSURE TRANSUCER
 Via an A/D - THE PRESSURE IS THE DELTA P AS FOUND IN *
 THE LIFT EQUATION; THIS DELTA P IS MULTIPLIED BY 2.31*
 AND THE STORED RESULT IN 'DELTAP' IS 10*(DELTA P) WITH*
 DELTA P IN UNITS OF FEET.

PRESS:
CALL STROBE :STROBE A/D'S PREPARATORY FOR CONVERSION
LD HL, PRESSR :LOAD IN PRESSURE RANGE ADDRESS
LD B, (HL) :GET PRESSURE RANGE OFF SWITCHED ROM'S
IN A, (8) :GET A/D DATA (DELTA P AS 8-BIT WORD)
CALL MUL8 :ANSWER = (PRANGE*DELTA P) IN HL PAIR
EX DE, HL :SHIFT INTO DE PAIR
LD BC, 3E3H :MULTIPICAND IS 1000 DECIMAL
CALL MUL16 :MULTIPLY - RESULT IN D,E,H,L
CALL REFORM
LD DE, 2B5DH :DIVIDE BY 11101 DECIMAL
CALL DIV16 :DIVIDE TO GET 10*(DELTA P) IN FEET IN HL PAIR
LD (DELTAP), HL :STORE THE 10*(DELTA P) RESULT IN RAM
RET

THIS ROUTINE ZEROS THE VELOCITY PRESSURE TRANSDUCER *
 AND SUBSEQUENTLY READS IT VIA AN A/D, CALCULATES THE*
 VELOCITY SQUARED USING V=1.548*(SQRT (PRESSURE)), *
 RESULT IN PVEL AND PVEL+2 IS 1,000,000*VEL SQUARED. *
 THE VELOCITY READING IS MODIFIED BY THE ZERO READING,*
 I.E. READING IS SUBTRACTED FROM THE ACTUAL A/D READING*

VELOC:
LD A, 4 :SET BIT 2 OF ACCUMULATOR
OUT (9), A :SIGNAL TO *56* SOLENOID- PROTECTION
CALL BIGCNT :WAIT APPROX. 2 SECONDS
LD A, 0CH :SET BITS 2 AND 3 OF ACCUMULATOR
OUT (9), A :LEAVE *56* ON AND TURN ON *14* SOLENOID-BLEED
CALL CNT17 :WAIT 17 SECONDS
LD A, 84H :LEAVE *56* ON AND TURN ON *23* SOLENOID-ZERO
OUT (9), A :AND TURN OFF *14* SOLENOID (BLEED FINISHED).
CALL BIGCNT :WAIT APPROX. 2 SECONDS
LD A, 80H :LEAVE *23* (ZERO SOLENOID) ON AND TURN OFF
OUT (9), A :*56* PROTECTION SOL. READY FOR ZERO READING
CALL CNT17 :WAIT TWO MINUTES
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL CNT17
CALL STROBE :STROBE A/D'S

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IN A:0DH;
LD (VELZER),A;
LD A,0;
OUT (9),A;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL CNT17;
CALL STROBE;
LD A,(VEL);
AND OFH;
LD B,A;
LD HL,VELM;
LD C,(HL);
LD A,(VELZER);
IN A,(0DH);
SUB E;
LD E,A;
LD D,(I);
CALL MUL16;
CALL REFORM;
LD DE,100H;
CALL DIV16;
LD BC,5D9BH;
CALL MUL16;
LD A,E;
LD E,D;
LD D,A;
LD (PVEL),DE;
LD A,L;
LD L,H;
LD H,A;
LD (PVEL+2),HL;
RET;

**********************************************************************
*THIS ROUTINE READS THE VELOCITY TRANSUDCER VIA AN A/D,*
*CALCULATING THE VELOCITY SQUARED USING*
*V=1.548*(SQRT(PRESSURE)),*
*RESULT IN PVEL AND PVEL+2 IS 1,000.000*VEL SQUARED. *
**********************************************************************

VELOC1:
LD A,0;
OUT (9),A;
CALL STROBE;
LD A,(VEL);
LD B,A;
LD HL,VELM;
LD C,(HL);
LD A,(VELZER);
IN A,(0DH);
SUB E;
LD E,A;
LD D,A;
LD (PVEL),DE;
LD A,L;
LD L,H;
LD H,A;
LD (PVEL+2),HL;
RET;
**LIFT:**

- **LD E,A:** Load into E register
- **LD D,0:** Zero D ready for multiply
- **CALL MUL16:** Result in D,E,H,L
- **CALL REFORM:**
- **LD DE,100H:** Divide by 256 decimal
- **CALL DIV16:** Result in HL pair is 100*Pressure(VEL)
- **EX DE,HL:** Put result into DE
- **LD BC,5098H:** Multiply by 23963 decimal
- **CALL MUL16:** Result in D,E,H,L is 1,000,000*VEL squared
- **LD A,0:** Store MSWord in PVEL. First switch D and E
- **LD D,A:**
- **LD (PVEL), DE:** Store LSWord in PVEL+2. Switch H and L first.
- **LD A,L:**
- **LD L,H:**
- **LD H,A:**
- **LD (PVEL+2), HL:**
- **RET:**

---

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>LD E,A</strong></td>
<td>Load into E register</td>
</tr>
<tr>
<td><strong>LD D,0</strong></td>
<td>Zero D ready for multiply</td>
</tr>
<tr>
<td><strong>CALL MUL16</strong></td>
<td>Result in D,E,H,L</td>
</tr>
<tr>
<td><strong>CALL REFORM</strong></td>
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<tr>
<td><strong>LD DE,100H</strong></td>
<td>Divide by 256 decimal</td>
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<td><strong>CALL DIV16</strong></td>
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<td><strong>LD (PVEL), DE</strong></td>
<td>Store LSWord in PVEL+2. Switch H and L first.</td>
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<tr>
<td><strong>LD A,L</strong></td>
<td></td>
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<tr>
<td><strong>LD L,H</strong></td>
<td></td>
</tr>
<tr>
<td><strong>LD H,A</strong></td>
<td></td>
</tr>
<tr>
<td><strong>LD (PVEL+2), HL</strong></td>
<td></td>
</tr>
<tr>
<td><strong>RET</strong></td>
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**LIFT:**

- **CALL REFORM:** Format D,E,H,L from VEL routine ready for div. |
- **LD DE,1923H:** Divide by 6435 decimal |
- **CALL DIV16:** Result is 10000*(V^2/64.35) |
- **LD DE,0:** Zero DE ready for another divide |
- **CALL REFORM:** |
- **LD DE,3E8H:** Divisor is 1000 decimal |
- **CALL DIV16:** Result in HL is 10*(V^2/64.35) |
- **LD DE,(DELTAP):** Get 10*(DELTAP) Pressure result from RAM |
- **ADD HL,DE:** HL = 10*(V^2/64.35 + 2.31*DELTAP) |
- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
- **LD A,(HEIGHT2):** Get LSBYTE of HEIGHT.H from switched ROM's |
- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

---

---

**LIFT:**

- **CALL REFORM:** Format D,E,H,L from VEL routine ready for div. |
- **LD DE,1923H:** Divide by 6435 decimal |
- **CALL DIV16:** Result is 10000*(V^2/64.35) |
- **LD DE,0:** Zero DE ready for another divide |
- **CALL REFORM:** |
- **LD DE,3E8H:** Divisor is 1000 decimal |
- **CALL DIV16:** Result in HL is 10*(V^2/64.35) |
- **LD DE,(DELTAP):** Get 10*(DELTAP) Pressure result from RAM |
- **ADD HL,DE:** HL = 10*(V^2/64.35 + 2.31*DELTAP) |
- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
- **LD A,(HEIGHT2):** Get LSBYTE of HEIGHT.H from switched ROM's |
- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

---

---

**FLOW:**

- **CALL REFORM:** Format D,E,H,L from VEL routine ready for div. |
- **LD DE,1923H:** Divide by 6435 decimal |
- **CALL DIV16:** Result is 10000*(V^2/64.35) |
- **LD DE,0:** Zero DE ready for another divide |
- **CALL REFORM:** |
- **LD DE,3E8H:** Divisor is 1000 decimal |
- **CALL DIV16:** Result in HL is 10*(V^2/64.35) |
- **LD DE,(DELTAP):** Get 10*(DELTAP) Pressure result from RAM |
- **ADD HL,DE:** HL = 10*(V^2/64.35 + 2.31*DELTAP) |
- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
- **LD A,(HEIGHT2):** Get LSBYTE of HEIGHT.H from switched ROM's |
- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

---

---

**EFFICIENCY:**

- **CALL REFORM:** Format D,E,H,L from VEL routine ready for div. |
- **LD DE,1923H:** Divide by 6435 decimal |
- **CALL DIV16:** Result is 10000*(V^2/64.35) |
- **LD DE,0:** Zero DE ready for another divide |
- **CALL REFORM:** |
- **LD DE,3E8H:** Divisor is 1000 decimal |
- **CALL DIV16:** Result in HL is 10*(V^2/64.35) |
- **LD DE,(DELTAP):** Get 10*(DELTAP) Pressure result from RAM |
- **ADD HL,DE:** HL = 10*(V^2/64.35 + 2.31*DELTAP) |
- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
- **LD A,(HEIGHT2):** Get LSBYTE of HEIGHT.H from switched ROM's |
- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

---

---

**FLOW:**

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- **LD DE,1923H:** Divide by 6435 decimal |
- **CALL DIV16:** Result is 10000*(V^2/64.35) |
- **LD DE,0:** Zero DE ready for another divide |
- **CALL REFORM:** |
- **LD DE,3E8H:** Divisor is 1000 decimal |
- **CALL DIV16:** Result in HL is 10*(V^2/64.35) |
- **LD DE,(DELTAP):** Get 10*(DELTAP) Pressure result from RAM |
- **ADD HL,DE:** HL = 10*(V^2/64.35 + 2.31*DELTAP) |
- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
- **LD A,(HEIGHT2):** Get LSBYTE of HEIGHT.H from switched ROM's |
- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

---

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**EFFICIENCY:**

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- **LD A,(HEIGHT1):** Get MSByte of HEIGHT.H off switched ROM's |
- **AND 1FH:** Mask 5 lower bits |
- **LD D,A:** Pass to D register |
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- **LD E,A:** |
- **ADD HL,DE:** HL has 10*(H + V^2/64.35 + 2.31*DELTAP) |
- **AND 1FH:** Which equals 10*LIFT |
- **LD (LIFTT), HL:** Store 10*LIFT in RAM location 'LIFT' |
- **RET:** |

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<tr>
<td><strong>LIFT</strong></td>
<td>(HEIGHT + V^2/64.35 + 2.31*(DELTAP)) * 10</td>
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<td><strong>FLOW</strong></td>
<td>(VELOCITY)*(CROSS-SECTIONAL AREA)</td>
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<td><strong>EFFICIENCY</strong></td>
<td>= (0.0846<em>FLOW</em>LIFT/(POWER IN))*100%</td>
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FLOW:
LD DE,0 :START SQUARE ROOT AT 0
SAME:
PUSH DE :MAKE COPY ON STACK
PUSH DE :MAKE ANOTHER COPY
POP BC :TRANSFER DE TO BC VIA STACK
CALL MUL16 :FIND SQUARE OF NUMBER - DEHL = DE*BC
LD A,E :NEXT THREE INSTRUCTIONS EXCHANGE D AND E REG'S
LD E,B
LD D,A
LD (PVELD),DE :SAVE MSWORD IN RAM LOCATION PVELD
LD A,L :NEXT THREE INSTRUCTIONS EXCHANGE H AND L REG'S
LD L,H
LD H.A
LD (PVELD+2),HL :SAVE LSWORD IN RAM LOCATION PVELD+2
LD DE,PVEL :GET ADDRESS OF 1,000,000*V^2 - MSBYTE
LD HL,PVELD :GET ADDRESS OF TRIAL Squared NUMBER - MSBYTE
LD C,4 :NUMBER OF BYTES FOR MULTIPLE BYTE SUBTRACT
CALL MULSUB :SUBTRACT IN MULTIPLE BYTE FASHION
JP C,OVERR :CHECK TO SEE IF RESULT IS MORE THAN SOURCE
POP DE :IF NO THEN GET THE OLD SQUARE ROOT BACK
INC DE :OLD VALUE IS INCREMENTED FOR NEXT RUN
JP SAME :BACK AGAIN FOR ANOTHER RUN
OVERR:
POP DE :YES, WE'VE GONE TOO FAR SO GET OLD SORT BACK
DEC DE :OLD VALUE MINUS ONE IS 1000*(SQUARE RO0T(V^2))
LD A,(PIPFAM) :LOAD MSBYTE OF PIPE FACTOR
AND 7 :MASK FOR LOWER 3 BITS
LD B,A
LD A,(PIPFAL) :LOAD LSBYTE OF PIPE FACTOR = 1000*ACTUAL VALUE
LD C,A
CALL MUL16 :RESULT IN DEHL IS 1,000,000*FLOW
CALL REFORM
LD DE,3E8H :DIVISOR IS 1,000 DECIMAL
CALL DIV16 :RESULT IN HL IS 1,000*FLOW
EX DE,HL :PUT IN DE
LD (FLOWW),DE :STORE 1000*FLOW IN RAM LOCATION 'FLOWW'
LD BC,(LIFTT) :GET 10*LIFT - MULTIPLIER
CALL MUL16 :RESULT IS 10,000*FLOW*LIFT IN DEHL
CALL REFORM
LD DE,(POWER) :GET 100*POWER IN
CALL DIV16 :RESULT IN HL PAIR IS 100*(FLOW*LIFT/KW)
EX DE,HL :PUT IN DE
LD BC,34EH :MULTIPLIER IS 846 DECIMAL
CALL MUL16 :RESULT IN DEHL IS 10,000*EFFICIENCY
CALL REFORM
LD DE,3E8H :DIVIDE BY 1000 DECIMAL
CALL DIV16 :RESULT IN HL PAIR IS 10*EFFICIENCY
RET

*******************************************************************
*THIS ROUTINE CONVERTS THE EFFICIENCY, POWER IN, LIFT*
*AND FLOW RESULTS INTO A BCD FORMAT AND Displays THE *
*SAME ON THE LED'S: THE BCD RESULTS ARE ALSO STORED IN *
*RAM TO AVOID PRINTING. NOTE THAT THIS ROUTINE IS TO *
*FOLLOW THE FLOW ROUTINE AS THE EFFICIENCY RESULT IS *
*PASSED TO THIS ROUTINE VIA THE HL REGISTER. *
*******************************************************************
LOAD IN RAM BCD BLOCK START
LD IX,RAMPT
CALL BCDCON
CALL LD IY,1200H
CALL CALL BCDCON
LD BC, (POWIN)
LD HL,(1
LD DE,OAH
CALL DIV16
LD IX,RAMPT+3
LD IY,1500H
CALL BCDCON
LD BC, (LIFT)
LD HL,(I
LD DE,OAH
CALL DIV16
LD IX,RAMPT+6
LD IY,1800H
CALL BCDCON
LD BC, (FLOW)
LD HL,(I
LD DE,OAH
CALL DIV16
LD IX,RAMPT+9
LD IY,2100H
CALL BCDCON
RET

COPY ROM PRINT BLOCK TO RAM PRINT BLOCK
CALL BLOCK
LD A,(SITNUM)
SRL A
SRL A
SRL A
RES 5,A
ADD A,30H
LD HL,RAMBLK+5
CALL REDCLK
ADD A,30H
LD (HL),A
LD B,0CH
CALL REDCLK
INC HL
DEC B

**************************************************************************************************
* THIS ROUTINE CHANNELS INFORMATION TO A PRINT BLOCK. ON COMMAND FROM THE REAL TIME CLOCK THIS PRINT BLOCK WILL BE SENT TO THE PRINTER SO AS TO OBTAIN A PERMANENT COPY OF EFFICIENCY, POWER IN, LIFT, AND FLOW AS WELL AS SITE NUMBER AND REAL TIME CLOCK INFORMATION. *
**************************************************************************************************

SITE: CALL BLOCK
LD A,(SITNUM)
SRL A
SRL A
RES 5,A
ADD A,30H
LD HL,RAMBLK+5
LD (HL),A
LD HL,RAMBLK+11H
LD B,0CH
CALL REDCLK
ADD A,30H
LD (HL),A
INC HL
DEC B
CALL REDCLK :READ FROM RTC
ADD A, 30H :ASCII-IZE
LD (HL), A :LOAD YEARS UNITS INTO PRINT BLOCK
LD IX, MONTH :TABLE POINTER FOR MONTHS
DEC E :NEXT RTC ADDRESS - MONTH TENS
DEC HL :NEXT PRINT BLOCK ADDRESS
DEC HL :NEXT PRINT BLOCK ADDRESS
DEC HL :NEXT PRINT BLOCK ADDRESS
DEC HL :NEXT PRINT BLOCK ADDRESS
LD E, 0 :ZERO E - IF NO DATE TENS THEN UNCHANGED
CALL REDCLK :READ THE RTC INFORMATION FOR MONTH
BIT 0, A :IS THE MONTH OCTOBER, NOVEMBER OR DECEMBER
JP Z, MTH :IF IT ISN'T THEN JUMP
LD E, 0AH :IF DATE TENS THEN CHANGE E TO 10 DECIMAL
DEC B :NEXT RTC ADDRESS - MONTH UNITS
MTH:
CALL REDCLK :LOOK AT MONTH UNITS IN RTC
ADD A, E :ADD 10 ON TO UNITS IF BIT 0 SET FROM TENS
LD E, A :HAVE NUMBER OF MONTH - 1 = JAN ETC - LOAD IN E
ADD A, A :DOUBLE A
ADD A, E :TRIPLE A
LD D, 0 :ZERO D REGISTER
LD E, A :PUT TRIPLED MONTH NUMBER BACK IN E
ADD IX, DE :ADD TRIPLED NUMBER TO MONTH TABLE POINTER
LD A, (IX) :IX CONTAINS OFFSET - LOAD FIRST LETTER INTO A
LD (HL), A :LOAD FIRST LETTER INTO PRINT BLOCK
INC HL :NEXT PRINT BLOCK ADDRESS
INC HL :NEXT PRINT BLOCK ADDRESS
LD A, (IX) :LOAD ACC. WITH NEXT LETTER
LD (HL), A :LOAD SECOND LETTER INTO PRINT BLOCK
INC HL :SIMILARLY FOR THIRD LETTER
INC IX :LOAD ACC. WITH THIRD LETTER
LD (HL), A :LOAD THIRD LETTER INTO PRINT BLOCK
DEC HL :MOVE TO NEXT PRINT BLOCK ADDRESS - DATE
DEC HL :POINT TO IN PRINT BLOCK
DEC B :LOOK AT TENS OF DATE IN RTC
CALL REDCLK :READ TENS OF DATE
AND 3 :MASK FOR 2 LOW SIGNIFICANT BITS
ADD A, 30H :ASCII-IZE
LD (HL), A :LOAD TENS OF DATE INTO PRINT BLOCK
INC HL :NEXT PRINT BLOCK ADDRESS
DEC B :LOOK AT DATE UNITS IN RTC
CALL REDCLK :READ THE RTC FOR DATE UNITS
ADD A, 30H :ASCII-IZE
LD (HL), A :LOAD DATE UNITS IN PRINT BLOCK
LD IX, WKDAY :POINT TO WEEKDAY TABLE START
DEC HL :POINT TO WEEKDAY IN PRINT BLOCK
DEC HL :POINT TO WEEKDAY IN PRINT BLOCK
DEC HL :POINT TO WEEKDAY LOCATION IN RTC
DEC H :POINT TO WEEKDAY LOCATION IN RTC
CALL REDCLK :READ THE WEEKDAY INFORMATION FROM RTC
ADD A, A :DOUBLE A
LD D, 0 :ZERO OUT D REGISTER
LD E, A :TRANSFER DOUBLED WEEKDAY INFORMATION INTO E
ADD IX, DE :IX NOW CONTAINS OFFSET FOR WEEKDAY LETTERS
LD A, (IX) :LOAD ASCII VALUE OF FIRST WEEKDAY LETTER TO A
LD (HL), A :PUT THAT FIRST LETTER INTO THE PRINT BLOCK
INC IX :POINT TO SECOND LETTER LOCATION IN PRINT BLOCK
INC IX :POINT TO NEXT LETTER OF WEEKDAY TABLE
LD A, (IX) :LOAD SECOND LETTER INTO PRINT BLOCK
LD (HL), A :LOAD INTO PRINT BLOCK
LD HL, RAMBLK+1FH  ; SET UP PRINT BLOCK FOR SECONDS UNITS
LD B, 0             ; SET UP_RTC ADDRESS POINTER FOR SECONDS UNITS
CALL HR              ; LOAD SECONDS UNITS AND SECONDS TENS
CALL HR              ; LOAD MINUTES UNITS AND MINUTES TENS
CALL HRMODE          ; LOAD HOURS UNITS AND HOURS TENS
LD IX, RAMPT         ; POINT TO START OF BCD CONVERTED VARIABLES
LD C, 0CH            ; SET COUNTER TO 12 DECIMAL - I.E. WE ARE GOING
NEXT:                ; NEXT LOCATION
LD A, (IX)           ; TO READ IN EFF, POWER, LIFT, FLOW, (IX) TO ACC.
ADD A, 30H           ; ASCII-IZE
LD (IX), A           ; PUT ASCII CONVERTED DATA BACK INTO LOCATION
INC IX               ; NEXT LOCATION
DEC C                ; DECREMENT COUNTER
JP NZ, NEXT          ; LOOP UNTIL ALL VARIABLES ASCII-IZED
LD HL, RAMPT         ; START OF VARIABLE LOCATION IN RAM
LD DE, RAMBLK+34H    ; PRINT BLOCK LOCATION FOR MS DIGIT - EFFICIENCY
LDI DE               ; LOAD MS DIGIT - EFFICIENCY
LDI DE               ; LOAD MIDDLE DIGIT - EFFICIENCY
INC DE               ; BUMP POINTER IN PRINT BLOCK
LDI DE               ; LOAD LS DIGIT - EFFICIENCY
LD HL, RAMPT+3       ; POWER IN RAM LOCATION
LD DE, RAMBLK+47H    ; PRINT BLOCK LOCATION FOR MS DIGIT - POWER IN
LDI DE               ; LOAD IN POWER IN AS DONE FOR EFFICIENCY
LDI DE               ; SAME FOR LIFT
LD DE, RAMBLK+59H    ; SAME FOR LIFT
LDI DE               ; AND ALSO FOR FLOW
LD DE, RAMBLK+6EH    ; AND ALSO FOR FLOW
LDI DE               ; POINT TO START OF PRINT BLOCK
LD HL, RAMBLK        ; NUMBER OF LINES TO PRINT
LD B, LINCNT         ; NUMBER OF BYTES PER LINE TO PRINT
LD C, RAMNUM         ; ZERO THE ACCUMULATOR
OUT (10H), A         ; PULSE THE DATA STROBE LOW
CALL COUNT           ; STROBE LOW FOR A TIME
LD A, (HL)           ; GET THE CHARACTER FROM THE PRINT BLOCK
SET 7, A             ; SET THE DATA STROBE HIGH ON EACH CHARACTER
OUT (10H), A         ; SEND TO PRINTER FOR PRINTING
INC HL               ; NEXT PRINT BLOCK LOCATION
DEC C                ; FINISHED ALL BYTES?
JP NZ, PRMORE        ; GO BACK FOR MORE PRINTING
LD A, 0              ; ZERO THE ACCUMULATOR
OUT (10H), A         ; PULSE THE DATA STROBE LOW
CALL COUNT           ; WAIT
LD A, 8DH            ; CARRIAGE RETURN
OUT (10H), A         ; WAIT A BIT LONGER
CALL BIGNCT          ; FINISHED ALL LINES?
DEC B                ; FINISHED ALL LINES?
JP NZ, PRINT         ; GO BACK IF NOT
LD A, 0              ; DO A CARRIAGE RETURN
OUT (10H), A         ; CARRIAGE RETURN
CALL BIGNCT          ;
**REDelV:**

**MN:**

********************************************************
*THE REDCLK ROUTINE READS THE REAL TIME CLOCK. *
********************************************************

```assembly
REDCLK:  LD  A, 10H ;STROBE HOLD LINE
           OUT (9), A
LD  A, 30H ;WAIT A SHORT TIME
MN:      DEC A
JP NZ, MN
LD  A, B ;GET ADDRESS FROM B REGISTER
OUT (11H), A ;SEND ADDRESS TO RTC
LD  A, 40H ;STROBE READ LINE ON RTC
OUT (9), A ;WAIT A REAL SHORT TIME
NOP
NOP
NOP
NOP
IN A, (11H) ;GET THE DATA FROM THE RTC
AND 0FH ;MASK FOR THE MSNIBBLE
SRL A ;RIGHT JUSTIFY
SRL A
SRL A
LD  C, A ;STORE RESULT TEMPORARILY
LD  A, 0 ;ZERO ACCUMULATOR
OUT (9), A ;PUT ALL RTC CONTROL LINES LOW
LD  A, C ;GET RESULT BACK
RET

********************************************************
*THE HR AND HRMOD ROUTINES UTILISE THE REDCLK ROUTINE *
*TO READ THE RTC BUT FURTHER MANIPULATE THE RTC DATA TO*
*THE CORRECT FORMAT. THE DATA IS ALSO ASCII-IZED AND *
*LOADED INTO THE PRINT BLOCK. *
********************************************************

**HR:**

CALL REDCLK ;READ THE REAL TIME CLOCK UNITS
ADD A, 30H ;ASCII-IZE
LD  (HL), A ;LOAD INTO THE PRINT BLOCK
DEC HL ;NEXT PRINT BLOCK ADDRESS
INC B ;NEXT RTC ADDRESS
CALL REDCLK ;READ THE TENS FROM THE RTC
ADD A, 30H ;ASCII-IZE
LD  (HL), A ;LOAD INTO THE PRINT BLOCK
DEC HL ;SET UP P/B ADDRESS FOR START OF NEXT CALL
DEC HL
INC B ;SET UP RTC ADDRESS FOR START OF NEXT CALL
RET

**HRMOD:**

CALL REDCLK ;READ RTC UNITS OF HOUR
ADD A, 30H ;ASCII-IZE
```

********************************************************

LD A,D ;TRANSFER MSBYTE OF START TIME TO ACCUMULATOR
SUB B ;SUBTRACT MSBYTE OF STOP TIME
JP P,POS ;IF SIGN POSITIVE THEN JUMP
LD HL,6364H ;LOAD HL WITH 99,100, I.E. H=99 AND L=100
OR A ;REFORMAT TO FIND DIFFERENCE. RESET CARRY
SBC HL,BC ;SUBTRACT BC FROM HL
ADD HL,DE ;ADD RESULT TO START TIME TO GET DIFFERENCE
JP FIN ;DONE FOR NOW

------------

LD A,E ;GET LSBYTE OF START TIME
SUB C ;SUBTRACT LSBYTE OF STOP TIME FROM START LSBYTE
JP P,POS1 ;IF POSITIVE SIGN THEN JUMP
LD A,E ;OTHERWISE GET LSBYTE OF START TIME BACK
ADD A,64H ;ADD 100 DECIMAL TO ACCUMULATOR
LD E,A ;PUT BACK IN E REGISTER
INC B ;COMPENSATE FOR 100 ADD BY ADD TO MSBYTE STOP T
JP TIMER ;RECYCLE

------------

LD A,L ;GET LSBYTE OF RESULT
SUB 64H ;SUBTRACT 100 DECIMAL
JP M,FIN ;IF NEGATIVE SIGN THEN BRANCH
LD L,A ;OTHERWISE LOAD BACK IN L
INC H ;INCREASE MSBYTE OF RESULT

------------

LD A,D ;GET MULTIPLIER TO ACC (I.E. NUMBER OF SECONDS)
LD B,64H ;LOAD MULTIPlicAND OF 100 DECIMAL INTO B REG
CALL MULB ;MULTIPLY
LD D,0 ;ZERO D REGISTER IN PREPARATION FOR ADD
ADD HL,DE ;HL CONTAINS HUNDREDTHS OF SECONDS ELAPSED
EX DE,HL ;PUT RESULT INTO DE REGISTER FOR RETURN
RET

********************************************************

THE FOLLOWING MULTIPLY ROUTINE HAS THE MULTIPLIER IN THE ACCUMULATOR AND MULTIPlicAND IN THE B REGISTER. IT IS AN UNSIGNED 8BIT X 8BIT ROUTINE WITH THE 16BIT RESULT ENDING UP IN THE HL REGISTER.
MUL8:
LD L, 0  ; CLEAR L
LD H, A  ; MULTIPLIER TO H
LD C, B  ; MULTIPLICAND TO C
LD B, 0  ; CLEAR B
LD A, 8  ; ITERATION COUNT

LOOP4:
ADD HL, HL  ; SHIFT LEFT ONE BIT
JP NC, JUMP1  ; GO IF NO CARRY
ADD HL, BC  ; ADD MULTIPLICAND TO PARTIAL PRODUCT

JUMP1:
DEC A  ; DECREMENT COUNT
JP NZ, LOOP4  ; GO IF NOT 8 ITERATIONS

MUL16:
LD A, 10H  ; ITERATION COUNTER
LD HL, 0  ; ZERO PRODUCT

CYCL:
EX DE, HL  ; EXCHANGE
ADD HL, HL  ; SHIFT LEFT ONE BIT
PUSH AF  ; SAVE CARRY
EX DE, HL  ; EXCHANGE
ADD HL, HL  ; SHIFT LEFT ONE BIT
JP NC, JUMP2  ; GO IF NO CARRY
INC DE  ; CARRY TO MSBYTES

JUMP2:
POP AF  ; GET CARRY
JP NC, JUMP3  ; GO IF NO CARRY
ADD HL, BC  ; ADD MULTIPLICAND
JP NC, JUMP3  ; GO IF NO CARRY
INC DE  ; CARRY TO MSBYTES

JUMP3:
DEC A  ; DECREMENT ITERATION COUNT
RET Z  ; RETURN IF DONE - RESULT IN DEHL
JP CYCL  ; CONTINUE

********************************************************
*THIS 16BIT X 16BIT UNSIGNED MULTIPLY MULTIPLIES THE *
*CONTENTS OF THE DE AND BC REGISTERS AND RETURNS THE *
*RESULT IN THE DEHL PAIRS *
********************************************************

LD A, (2400H)  ; STOBE A/D'S
LD DE, 20H  ; USE DELAY TIMER TO MEET CONVERTER SET UP

LOOPW2:
DEC DE  ; AND CONVERSION TIMES
LD A, OFFH

CIRC2:
DEC A  ;
JP NZ, CIRC2
XOR A
CP D
JP NZ, LOOPW2
RET

********************************************************
*THE FOLLOWING ROUTINE STROBES THE ANALOG TO DIGITAL *
*CONVERTERS - MEMORY MAPPED ADDRESS IS 2400H. *
********************************************************

STROBE:
**THE WRICLK ROUTINE IS USED TO INITIALIZE THE REAL TIME CLOCK UPON FIRST POWER ON OR WHEN NECESSARY. THE RTC REGISTERS ARE LOADED WITH THE ACTUAL TIME OF INITIALIZATION; THIS INFORMATION IS SET ON THE SWITCHED ROM'S ON POWER UP WITH THE RTC FLAG SET.**

WRICLK:

LD A, 10H ; HOLD PULSE
OUT (9), A
LD A, 20H ; TIMER
MIN:

DEC A
JP NZ, MIN
LD A, B ; ADDRESS
OUT (11H), A
LD A, 30H ; WRITE TO RTC
OUT (9), A
LD A, 0
OUT (9), A ; ALL CONTROL SIGNALS LOW AGAIN
RET

**THE 31BIT BY 15BIT DIVIDE ROUTINE IS UNSIGNED AND DIVIDES THE DATA IN THE HLB'C' REGISTERS BY DATA IN THE DE PAIR. TEMPORARY OUTPUT IS IN H'L'D'E' AND E' IS TESTED TO SEE IF THERE SHOULD BE ROUNDING UP. FINAL OUTPUT IS IN THE HL REGISTER PAIR.**

DIV16:

EXX ; EXCHANGE REGISTER BANKS
LD HL, 0 ; ZERO RESULT REGISTERS
LD DE, 0
EXX
LD B, 19H ; CYCLE 25 TIMES
LD (DEN), DE ; STORE DENOMINATOR
DIV:

LD DE, (DEN) ; LOAD DENOMINATOR INTO DE
XOR A ; CLEAR CARRY
LD (NUM), HL ; SAVE MSWORD OF NUMERATOR
SBC HL, DE ; SUBTRACT
JP C, VOID ; IF DEN>NUM THEN SHIFT ZERO INTO RESULT
SCF ; ELSE SHIFT ONE IN

WUN:

EXX
RL E ; SHIFT SHIFTED BIT ABOVE THROUGH ALL REGISTERS
RL D
RL L
RL H
SLA C ; SHIFT ZERO INTO NUMERATOR
RL E
EXX
RL L
RL H
DJNZ DIV ; ROUND
JP VOID
VOID:

XOR A ; CLEAR CARRY
LD HL, (NUM) ; GET NUMERATOR BACK
JP WUN
ROUND:  EXX
LD  A,E       ;GET REMAINDER FROM E'
CP  80H       ;COMPARE
JP  M.LEAVE   ;IF MINUS THEN LEAVE AS IS
INC  D       ;IF D>=0.5 THEN INCREMENT D'
LEAVE:  LD  A,L  ;PUT L' IN ACCUMULATOR
EXX  ;GET MAIN BANK
LD  H,A       ;LOAD H WITH L'
EXX  ;GET ALTERNATE BANK
LD  A,D       ;PUT D' IN ACCUMULATOR
EXX  ;GET MAIN BANK
LD  L,A       ;LOAD L WITH D'
RET

********************************************************
*THE REFORM ROUTINE SWITCHES THE DE AND HL REGISTERS *
*AND TAKES THE NEW LSWORD IN DE AND PUTS IT IN B'C' *
********************************************************
REFORM:  EX  DE,HL  ;PUT DE IN HL PAIR
LD  (TEMP1),DE  ;STORE LSWORD TEMPORARILY
EXX  ;LOAD DE INTO B'C'
LD  BC,(TEMP1)  ;LOAD BC WITH NUMBER OF BYTES TO TRANSFER
EXX  ;BLOCK TRANSFER
RET

********************************************************
*THE BLOCK ROUTINE TRANSFERS THE PRINT BLOCK FROM ROM *
*TO RAM READY FOR THE NUMERICS TO BE LOADED INTO THE *
*APPROPRIATE AREAS. *
********************************************************
BLOCK:  LD  DE,RAMBLK  ;LOAD DE WITH DESTINATION RAM POINTER
LD  HL,PRBLK  ;LOAD HL WITH ORIGIN ROM POINTER
LD  BC,RAMCNT  ;LOAD BC WITH NUMBER OF BYTES TO TRANSFER
LDIR  ;BLOCK TRANSFER
RET

********************************************************
*THE LORTC ROUTINE TAKES THE DATA ON THE SWITCHED ROM'S* 
*AND WRITES THIS INFORMATION TO THE RTC WHEN THE RTC *
*FLAG IS HIGH. THE SWITCH DATA SHOULD BE SET UP TO *
*CONTAIN THE ACTUAL TIME OF INITIALIZATION.*
********************************************************
LORTC:  LD  A,(RTCFLG)  ;SEE IF RTC FLAG IS SET
BIT  7,A
RET  2       ;IF NOT SET THEN NO NEED TO INITIALISE RTC
LD A,00FH  ;SET UP P101 AND P103, P103 CHANNEL B TO
OUT (13H),A  ;HAVE ALL ITS PINS DESIGNATED AS OUTPUTS
LD A,0      
OUT (13H),A  
LD B,0      
CALL WRICLK  ;GET RTC ADDRESS
LD B,1      
CALL WRICLK  ;TENS OF SECONDS ADDRESS
LD C,2      
CALL WRICLK  ;NEXT RTC ADDRESS
LD HL,MONMIN  ;GET SWITCHED ROM ADDRESS
TM:  LD A,(HL)  ;GET DATA FROM SWITCHED ROM - PUT IN ACC
AND OFH  ;GET MSDIGIT
OR C  ;ADD TO ADDRESS NIBBLE
LD B,A   ;TRANSFER TO B TO PASS TO WRICLK ROUTINE
CALL WRICLK  ;LOAD INTO RTC
INC H  ;NEXT SWITCH ADDRESS
INC C  ;NEXT RTC ADDRESS
LD A,9  ;ADDRESS COUNTER
CP C  ;FINISHED YET?
JP NZ,TM  ;NO, SO GO BACK
LD HL,RTCFLG  ;YES, SO LET'S START ON LSNIBBLE
TIM:  LD A,(HL)  ;REPEAT ABOVE PROCEDURE FOR LSNIBBLES
AND OFH  ;MASK FOR LOWER 4 BITS
SLA A  ;LEFT JUSTIFY
SLA A
SLA A
SLA A
OR C  ;JOIN TO ADDRESS NIBBLE
LD B,A   ;TRANSFER TO B TO PASS TO WRICLK
CALL WRICLK
INC H  ;NEXT SWITCH ADDRESS
INC C  ;NEXT RTC ADDRESS
LD A,0DH  ;ADDRESS COUNTER
CP C
JP NZ,TIM  ;NOT FINISHED SO GO BACK
LD A,00FH
OUT (13H),A
LD A,OFH
OUT (13H),A
RET

********************************************************************
*THE BCDCON ROUTINE USES THE BCD ROUTINE TO CONVERT THE*
*BINARY NUMBER IN THE HL PAIR TO A BCD NUMBER, THIS DATA*
*IS THEN LOADED INTO RAM AS WELL AS BEING DISPLAYED ON*
*LED'S.************************************************************************
********************************************************************

BCDCON:  CALL BCD  ;CONVERT THE BINARY NUMBER TO BCD
PUSH IY  ;TRANSFER IY CONTENTS TO HL
POP HL
EXX
LD A,C  ;GET DIGIT THREE FROM C'
EXX
AND OFH  ;MASK FOR LOWER 4 BITS
LD (HL),A  ;MSDIGIT INTO LED
LD (IX),A  ;LOAD RAMBLOCK WITH MSDIGIT
EXX
LD A,D  ;GET NEXT SIGNIFICANT DIGIT FROM D'
EXX

79
BCD:

TENS:

THOUS:

HUND:

TEN:

********************************************************

*THE BCD ROUTINE CONVERTS A BINARY NUMBER TO BCD FORMAT*

*NUMBER IN HL REGISTER PAIR. RESULT AS *

*FOLLOWS: DIGIT 5 - LOWER 4 BITS OF REG B' *

* 4 - HIGH 4 BITS OF REG C' *

* 3 - LOWER 4 BITS OF REG C' *

* 2 - HIGH 4 BITS OF REG D' *

* 1 - LOWER 4 BITS OF REG D' *

*ONLY THE DIGITS 3,2,1 ARE USED. *

********************************************************

BCD: 

LD DE,2710H ;LOAD DE WITH 10,000 DECIMAL

CALL UNIT ;SUBTRACT POWERS OF 10 FROM NUMBER

EXX

LD B,A ;RESULT IN ALTERNATE B'

EXX

LD DE,3E8H ;1000 DECIMAL

CALL UNIT

CALL MODIFY ;ROTATE LOWER BYTE TO UPPER POSITION

EXX

LD C,A ;DIGIT 4 IN UPPER NIBBLE OF C'

EXX

LD DE,64H ;100 DECIMAL

CALL UNIT

EXX

OR C ;3 AND 4 DIGITS COMBINED

LD C,A

EXX

LD DE,0AH ;10 DECIMAL

CALL UNIT

CALL MODIFY

OR L ;1 AND 2 DIGITS COMBINED

EXX

LD D,A ;RESULT IN D'

EXX

RET

********************************************************

*THE UNIT ROUTINE SUBTRACTS POWERS OF 10 FROM THE NUMBER *

*IN THE HL PAIR. *

********************************************************
UNIT: LD A, OFFH ; COUNTER = -1
ABOVE: INC A ; INCREMENT COUNTER
OR A ; CARRY CLEARED
SBC HL, DE ; SUBTRACT POWERS OF 10
JR NC, ABOVE ; CONTINUE SUBTRACTING UNTIL RESULT IS NEGATIVE
ADD HL, DE ; RESTORE NUMBER IF OPERATION WAS NEGATIVE
RET

********************************************************
*THE MOD ROUTINE ROTATES THE NUMBER IN THE ACCUMULATOR *
*FOUR PLACES TO THE LEFT. *
********************************************************
MODIFY: AND OFH ; CLEAR UPPER BITS
RLCA
RLCA
RLCA
RLCA
RET

********************************************************
*THE MULSUB ROUTINE ACCOMPLISHES A MULTIPLE SUBTRACT. *
*THE HL REGISTER POINTS TO THE DESTINATION MSBYTE AND *
*THE DE TO THE SOURCE MSBYTE. THE DESTINATION OPERAND *
*IS SUBTRACTED FROM THE SOURCE AND THE RESULT PLACED *
*BACK IN THE DESTINATION LOCATION. THE C REGISTER HAS *
*THE WIDTH IN BYTES OF THE SOURCE AND DESTINATION OPER-
*ANDS. THE CARRY IS SET TO REFLECT THE LAST (MS) CARRY*
********************************************************
MULSUB: LD B, 0 ; CLEAR B - C CONTAINS NUMBER OF BYTES
ADD HL, BC ; POINT TO DESTINATION LSBYTE+1
DEC HL ; POINT TO LSBYTE
EX DE, HL
ADD HL, BC ; POINT TO SOURCE LSBYTE+1
DEC HL ; LSBYTE
EX DE, HL
OR A ; CLEAR BORROW
GOMORE: LD A, (DE) ; GET SOURCE BYTE
SBC A, (HL) ; SOURCE MINUS DESTINATION MINUS CARRY
LD (HL), A ; STORE RESULT
DEC HL ; DESTINATION POINTER DECREMENTED
DEC DE ; SOURCE POINTER DECREMENTED
DEC C ; BYTE COUNT DECREMENTED
JR NZ, GOMORE ; GO IF NOT ALL SUBTRACTS DONE
RET
***************
*DELAY ROUTINES*
***************

COUNT:  LD DE,25H
        DEC  DE
        LD A,OFFH
LOOPW:  DEC  A
        JP  NZ,CIRC
        XOR A
        CP  D
        JP  NZ,LOOPW
        CP  E
        JP  NZ,LOOPW
        RET

BIGCNT: LD DE,500H
        DEC  DE
        LD A,OFFH
        JP  NZ,CIRC1
        XOR A
        CP  D
        JP  NZ,LOOPW1
        CP  E
        JP  NZ,LOOPW1
        RET

CNT17:  LD DE,2CDOH
        DEC  DE
        LD A,OFFH
        JP  NZ,CIRC3
        XOR A
        CP  D
        JP  NZ,LOOPW3
        CP  E
        JP  NZ,LOOPW3
        RET

FIVMIN:  LD E,3
        DEC  E
        LD HL,OFFFH
LPX4:    DEC  HL
        LD B,OFFH
LPX5:    DEC  B
        JP  NZ,LPX6
        XOR A
        CP  H
        JP  NZ,LPX5
        CP  L
        JP  NZ,LPX5
THE ZERPRI ROUTINE MAKES THE DECISION TO DO A BLEED/ZERO AND PRINT OUT THE PRINT BLOCK BASED ON PRIFLG BEING SET. THE OPERATION WILL OCCUR BY EXTERNAL MANUAL OPERATION AS INITIATED BY THE 1/DAY-CONTINUOUS SWITCH OR ONCE EVERY DAY AS SET ON THE TIME SWITCH FOUND IN THE SWITCHED ROM AREA.

ZERPRI: IN A,(9) ;GET PRINT FLAG INFORMATION FROM PIO BIT 1,A ;LOOK AT APPROPRIATE BIT JP NZ,PRINT1 ;IF IT'S SET THEN ZERO/PRINT THREE TIMES LD B,4 ;GET HOURS - UNITS OFF RTC CALL REDCLK ;READ THE RTC LD D,A ;SAVE HOURS - UNITS IN D REGISTER LD B,5 ;GET HOURS - TENS RTC CALL REDCLK ;READ THE RTC AND 3 ;MASK FOR TWO LOWER BITS LD B,0AH ;MULTIPLICAND IN B CALL MUL8 ;HL CONTAINS TENS OF HOURS TIMES 10 DECIMAL LD A,L ;STORE IN ACCUMULATOR ADD A,D ;ADD UNITS TO TENS LD C,A ;STORE IN C LD A,(PRITIM) ;GET PRINT TIME OFF SWITCHED ROMS SRL A ;RIGHT JUSTIFY SRL A SRL A CP C ;ARE WE AT ZERO/PRINT HOUR? JP NZ,LAST1 ;IF NOT, THEN BRANCH LD A,(PRIFLG) ;LOOK AT ZERO/PRINT FLAG TO SEE IF SET OR A ;SET/RESET ZERO IN ZERO/PRINT FLAG RET NZ ;IF SET THEN DON'T ZERO/PRINT AGAIN LD A,OFFH ;SET ACCUMULATOR TO ALL ONES LD (PRIFLG),A ;ZERO/PRINT FLAG NOT SET PREVIOUSLY, SO SET NOW PRINT1: CALL SUBPRO ;ZERO AND PRINT THREE TIMES CALL SUBPRO CALL SUBPRO RET ;DONE THREE TIMES, LET'S LEAVE LAST1: LD A,0 ;ZERO ACCUMULATOR LD (PRIFLG),A ;RESET PRINT FLAG RET

THE SUBPROG ROUTINE CALLS THE BULK OF THE MAIN PROGRAM AND IS USED IN THE ZERO/PRINT ROUTINE 'ZERPRI' TO RUN THE SYSTEM THROUGH A BLEED, ZERO, AND DATA SEQUENCE THREE TIMES, THE RESULTS BEING PRINTED OUT EACH TIME.
CALL PKLESS
CALL VELOC
CALL LIFT
CALL FLOW
CALL DISP
CALL SITE
RET

*********************************************************
*THE RETN ROUTINE SIMPLY DISCOVERS WHETHER A RETURN TO *
*THE POWER IN TESTK ROUTINE WILL ENABLE THE TIMER TO BE*  
*$STARTED WITH THE RISING EDGE OF THE KWH INPUT SIGNAL *  
*$AND THUS MEASURE THE FULL CORRECT TIME.               *
*********************************************************

RETN:  IN  A, (9)  ;LOOK AT THE KWH SWITCH
       BIT  0, A    ;INFORMATION IN BIT ZERO
       JP  NZ, RETN ;IF STILL HIGH THEN WAIT UNTIL LOW
       RET

********
*TABLES*
********

WKDAY:  DB  'SUMOTUWETHFSSA'
MONTH:   DB  'JANFEBMARAPRMAJUNJULAUGSEPONOVDEC'
PRBLK:   DB  'SITE#X XX XXX XXX XX'
         DB  'TIME XX:XX:XX   '
         DB  'EFFICIENCY(%) XX.X   '
         DB  'POWER IN (KW) XX.X   '
         DB  'LIFT (FEET) XXX   '
         DB  'FLOW (CFS) X.XX   '

.DEPHASE
END