ASSESSMENT OF THE MECH 2002 WIRE FEED RATE METER

For Dallas Koop
Shop Foreman, Kalamalka Industries

Prepared by Jordan Clarke, Chris Down,
Justin Mckellar, and Tim Staal

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SUMMARY

This report assesses the Mech 2002 welding wire feed rate meter, which was constructed to accurately measure welding wire feed rates at Kalamalka Industries. The meter had to meet the following criteria:

- The meter must be accurate to within 4% at a feed rate of 250 inches per minute.
- The meter must be small and portable.
- The meter must withstand the plant atmosphere, which may contain dust and other particles.
- The meter must be quick and easy to use.

The meter was designed around a digital Vetta bicycle speedometer. Replacing or modifying key components, while ignoring the decimal in the display, cause the speedometer to read wire feed rate directly in inches per minute.

The meter was manufactured from ‘off the shelf’ parts purchased from local stores. Some of these parts had to be modified before use, which was done in the Mechanical Engineering shop at OUC. With some minor trial and error, the final assembly of the meter was completed under budget.

A relevant and unique testing procedure was developed to assess the meter’s accuracy. The variable speed drive on a milling machine was used to test the meter through its full design operating range. An elastic band was used as a belt to connect the meter to the mill drive. By counting the number of revolutions of the meter wheel in a given time period and knowing the diameter of the wheel, the actual linear speed was calculated. This calculated speed was compared to the meter’s readout to determine the instrument’s accuracy. The meter was also tested on an actual welder to confirm accuracy and to check if the instrument was easy to use.

An assessment of the Mech 2002 welding wire feed rate meter, has determined that with regards to accuracy, ease of use, and cost, the meter will meet the needs of Kalamalka Industries. The Mech 2002’s long-term reliability has not yet been determined due to time constraints. Increased accuracy will be gained by replacing the Vetta bicycle speedometer with a speedometer of increased resolution and changes could also be made to improve the appearance and, possibly, the durability of the meter.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Tables

1.0 INTRODUCTION

1.1 The Problem

The subject of this report resulted from inquiries made to Henry Murphy, an OUC instructor. Henry, who is the retired plant manager of Kalamalka Industries, stated that Kalamalka often has problems that go unresolved for great lengths of time because of their relative lack of importance. These problems can range from basic maintenance such as leaky faucets in bathrooms, to welders that do not weld a perfectly straight bead. Dallas Koop, who is the lead foreman of the Kalamalka plant, was contacted to see if there were any problems that would suit an English report. After a brief meeting and a tour of the plant, Dallas introduced the problem he had regarding the feed rate of the welders. When inspectors visit the plant, one part of their examination is to ensure that all of the welders feed wire at a constant and measurable rate. To measure the rate, Dallas feeds a certain length of wire and times how long it took this length unwind. A simple division gives him a rough estimate, but it is not accurate enough to keep the inspectors happy. Dallas requested that a method be found to accurately measure the feed rate of the welders at Kalamalka Industries. He knew that suitable measuring instruments already existed, but he had not had time to research which one best suited his needs.

1.2 A Solution

There were two available solutions to the problem; either research feed rate meters that are commercially available and determine which one was the most feasible, or design and manufacture a meter that would fulfill the set of requirements listed in the next section.

Researching the types of commercial feed rate meters showed that the few available instruments are too expensive. Most commercial meters are priced in the range of $750 to $3000 and many are made to be permanently mounted on one welder. These factors led to the decision to design and manufacture a wire feed rate meter.

1.3 Design Criteria

The only direct requirement received from Kalamalka was with regards to the meter's accuracy. However, other unstated parameters were also important:

- The instrument must measure the feed rate accurately within 4% at a rate between 50 and 750 inches per minute.
- The instrument must be small and portable.
- The instrument must withstand plant atmosphere including resisting dust, and being dropped.
- The instrument must be inexpensive.

More subjectively, the instrument must be quick and easy to use.

2.0 DESIGN

2.1 Design Research and Selection

Selecting a method of measuring the welding wire feed rate was the first step in planning the design of the Mech 2002. The basic design of the meter involves a metering wheel which, when placed on the welding wire, rolls as the wire passes by. Determining the wire feed rate requires measuring the angular the velocity of this wheel and converting this measurement into an inches per minute (ipm) reading. As mentioned in the previous section, the most important criteria required for the meter design were accuracy, range, cost, and ease of use. These parameters formed a basis for researching various design ideas such as:

- using a surface wheel measuring device which is rolled on a surface and gives a distance measurement.
- using a meter similar to those used to measure rope purchased at a hardware store.
- using an electrical generator with the idea that the faster the wheel turns, the higher the voltage produced.
- using a digital bicycle speedometer.

The first two ideas showed promise in terms of simplicity and cost but both devices gave a linear measurement only. To produce a wire feed rate, the time must be measured and the rate calculated. This would be too laborious. The third idea of using an electrical generator eliminated this drawback and would give a direct readout of wire feed rate. However, complexity and cost would increase and converting the voltage reading to a wire feed rate reading would be difficult. The last idea of using a digital bicycle computer best met the requirements of the wire feed rate meter design. The bike speedometer was simple, inexpensive, accurate, and gives a direct readout of linear speed. For these reasons, the digital bicycle computer was chosen as the basis for the Mech 2002 design.

2.2 Design Planning and Completion

2.2.1 Design problems

Several problems had to be overcome to complete the conversion of the bicycle speedometer to a welding wire feed rate meter. The Mech 2002 must be compact enough to easily hold in one hand and to allow easy access to the welding wire with the metering wheel. Due to these size restrictions, some of the bike speedometer components were incompatible with the Mech 2002 design. The speedometer uses a magnet mounted on a spoke and a switch mounted on the front fork. As the bike wheel turns, the magnet passes the switch, which opens and closes. The frequency at which the circuit is switched on and off is converted by the speedometer to a kilometer per hour (kph) reading. This magnet/switch combination was too bulky to use in the wire meter. A smaller device was required. Rick Gostlin, a fellow student and an electronics engineering graduate, suggested using an infrared optical sensor. This device is very compact. When the sensor's infrared beam is interrupted, the electric current passing through the device is also interrupted and therefore, the switching frequency is equal to the frequency at which the optical beam is broken. The question was how to cause this interruption. We decided to mount a second wheel on the same shaft as the metering wheel and to use this second wheel to interrupt the beam.

2.2.2 Slotted sensor wheel

The layout of this interrupting wheel became the next step in completing the design. This wheel had slots cut in its perimeter and as the wheel spins past the optical sensor, these slots break the infrared beam which in turn breaks the electric circuit. The number of slots determines the frequency at which the circuit is broken and calculating this number requires looking back at what the meter is measuring. The Mech 2002 measures welding wire feed rates from 50 to 750 ipm. However, the bicycle speedometer measures kph from 0 to 99.5 kph in 0.5 kph increments. To allow a direct reading in ipm, the decimal must be ignored and kph must be read as ipm. For example, 30.0 kph would read as 300 ipm. For the readings to match in this way, the switching frequency of a bike traveling at 30 kph must equal the switching frequency of the optical sensor as the meter's wheels are spun by the welding wire traveling at 300 ipm. The number of slots cut in the interrupting wheel determines if the readings will match. The bike and meter wheel diameters are very different, and the meter reading of ipm is different than the speedometer reading of kph. This means that several calculations are required to determine the required number of slots. These calculations are shown in Appendix C and the results indicate that seven slots were required in the perimeter of the interrupting wheel. The finished wheel is shown in Figure 1.

Figure 1: Slotted Interrupting Wheel

2.2.3 Electronic design

Rick Gostlin was instrumental in designing the electronic parts of the meter. The bicycle computer requires a constant voltage applied to it, otherwise it loses its memory and the bike wheel circumference would have to be re-input every time the meter is turned on. The computer has an automatic shut down mode after a period of inactivity and does not need a switch. Conversely, the infrared sensor needs to be shut off or the battery life will be very short. This meant the battery voltage had to be split in two; a constant supply to the meter and a switched supply to the sensor. The electronics schematic is shown below in Figure 2. The part of the circuit to the left of the red line supplies the voltage to the computer while the part to the right supplies the sensor. In each case, the battery voltage is stepped down to the voltage required for either the meter or the sensor.

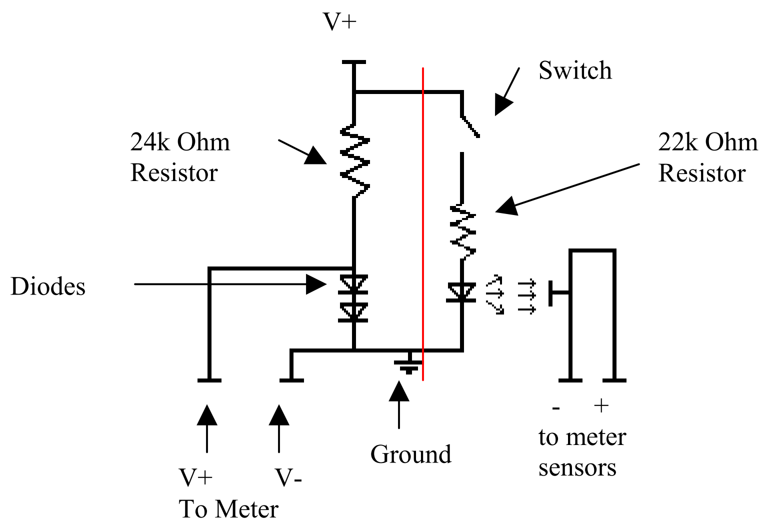

Figure 2: Electronics Schematic

The remaining components required to complete the meter are or are made from 'off the shelf' parts and as such do not require the design work described in the preceding sections. To avoid repetition, descriptions of these components are left to the next section of the report.

3.0 MANUFACTURING THE METER

Producing the wire feed rate meter involved assembling purchased parts as well as fabricating parts from scratch. Most of the parts used were bought at Princess Auto, Radio Shack, and Interior Electronics. Some of the components used in the meter are simple parts that have been modified and others have been made from scratch. The building of the meter can be divided into the mechanical components and the electrical components.

3.1 Electrical Components

The electrical components in the wire feed rate meter consist of a circuit board containing: the infrared sensor, a battery; a power switch, and a Vetta C-10 bicycle computer. Richard Gostlin, an Electronics Engineering Technologist, helped to design the electrical components as well as to build the circuit board.

Manufacturing the electrical components began with building a template circuit board to test if the design would work. Figure 3 shows the early template circuit board. From this point the working circuit board was made small enough to fit inside the box containing all the parts of the meter. The bicycle computer, located outside the box, is connected to the meter with a computer keyboard cord.

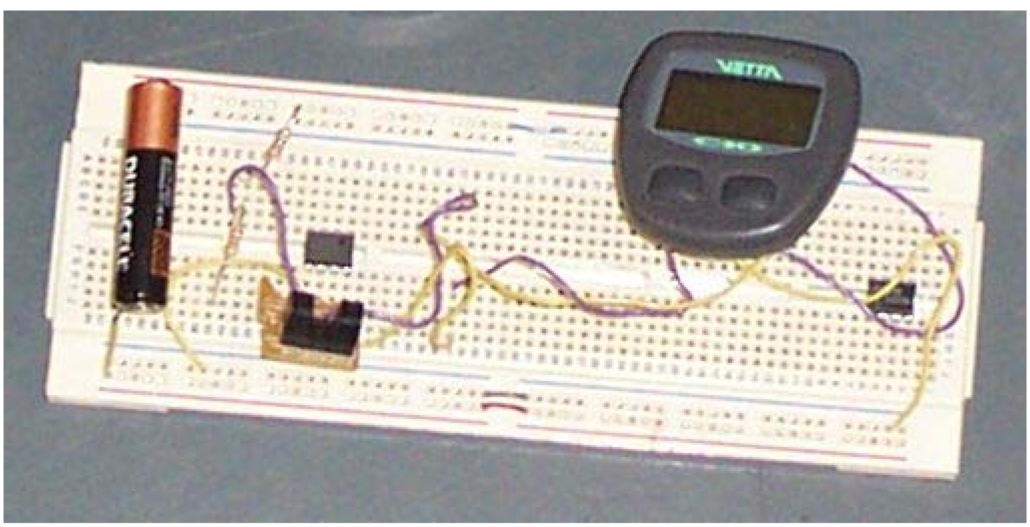

Figure 3: Template Circuit Board

The circuit board is fabricated from a blank board bought at Radio Shack and a few standard components. The electric sensor eye is from a VCR and Richard supplied the other components, two resistors and two diodes. Figure 4 shows the working board.

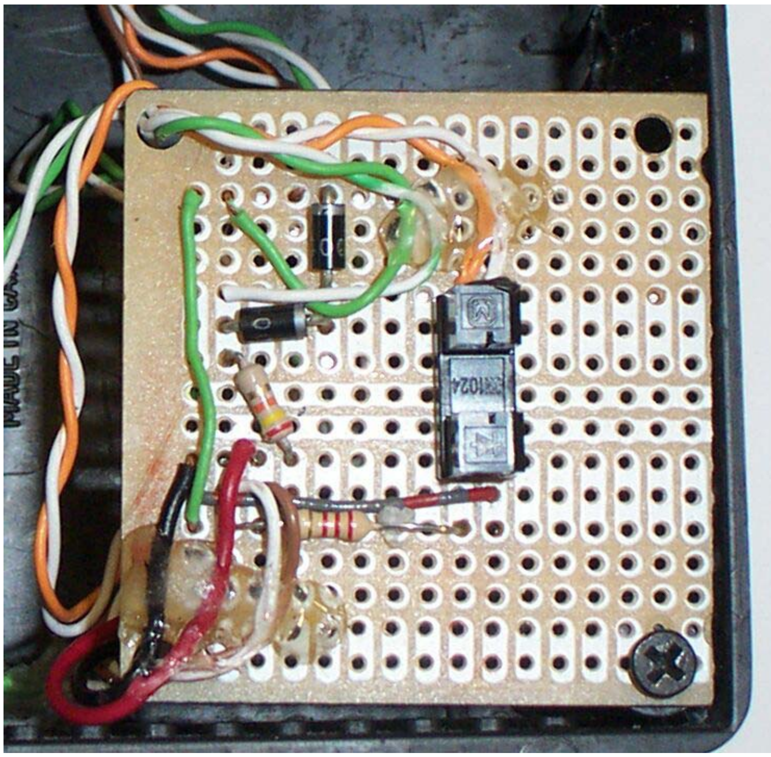

Figure 4: Circuit Board

3.2 Mechanical Components

The mechanical parts used in the meter were bought at local stores or were pieces that we already had at home. The mechanical parts are:

Plastic electrical box
Wire wheel
Sensor wheel
Two abec-1 skateboard bearings
Two Ultra High Molecular Weight plastic (UHMW) bearing retainers
UHMW circuit board retainer
5/16” shaft and collar

The electrical box was purchased from Interior Electronics. This size box was chosen because it is the smallest box large enough to hold the sensor wheel. The box is plastic, so it was easy to drill the holes for the shaft and the wires.

The wire wheel was fabricated from a rubber caster wheel purchased from Princess Auto. To better suit the application, the wheel was then modified by mounting it on the shaft and turning it in the lathe. A groove was put in middle of the outer surface of the wheel to guide the wire and to help keep the meter perpendicular to the direction of feed. Next, some of the center portion of the wheel was thinned down to reduce the moment of inertia of the wheel. This thinning was done to reduce the over all drag that the meter puts on the wire.

The sensor wheel was also made from a castor wheel. The plastic castor was machined in the same manner as the wire feed wheel, in the lathe. The sensor wheel was turned down to a thin disk that fits inside the electric eye as can be seen in Figure 5. After turning the wheel to the proper thickness and diameter, 7 equally spaced holes were drilled the wheel. These holes were made into slots by cutting the wheel with an air-powered grinder. Figure 6 shows the completed sensor wheel.

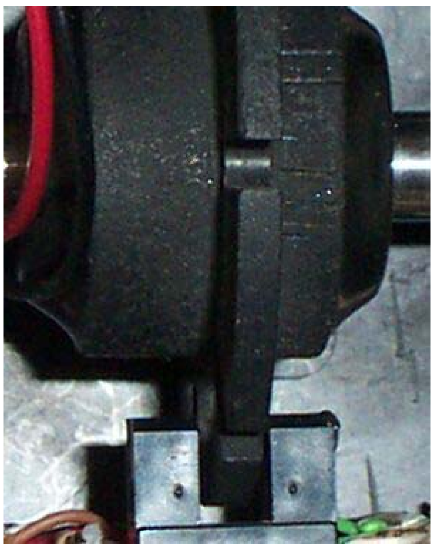

Figure 5: Sensor Wheel in the Electric Eye

Figure 6: Sensor Wheel

Two abec-1 skateboard bearings are used to support the shaft in the box,. Originally, we planned to make bushings out of the UMHW but this method caused too much rolling resistance. The UMHW was used to support the bearing and to attach the bearings to the box. Shaping the UMHW was done with a band saw. Mounting the bearings in the UMHW required two 0.875-inch holes, which were drilled with a spade bit. The UMHW was also used to mound the circuit board. It was cut to size with a band saw and slotted to allow the circuit board to slide in and out.

A 5/16” steel shaft connects the wire feed wheel and the sensor wheel. The shaft was turned down to 5/16” from some readily available 3/8” cold rolled stock. The wire wheel was secured on the end of the shaft by turning the shaft smaller and cutting ¼” threads into the end of the shaft. The shaft is held in place by a collar that butts up against the first bearing. The finished shaft and collar can be seen in Figure **7**.

Figure 7: Shaft and Locking Collar

3.3 Assembly

All of the components listed above are easily assembled to make the wire feed rate meter. Figure 8 shows all the components disassembled.

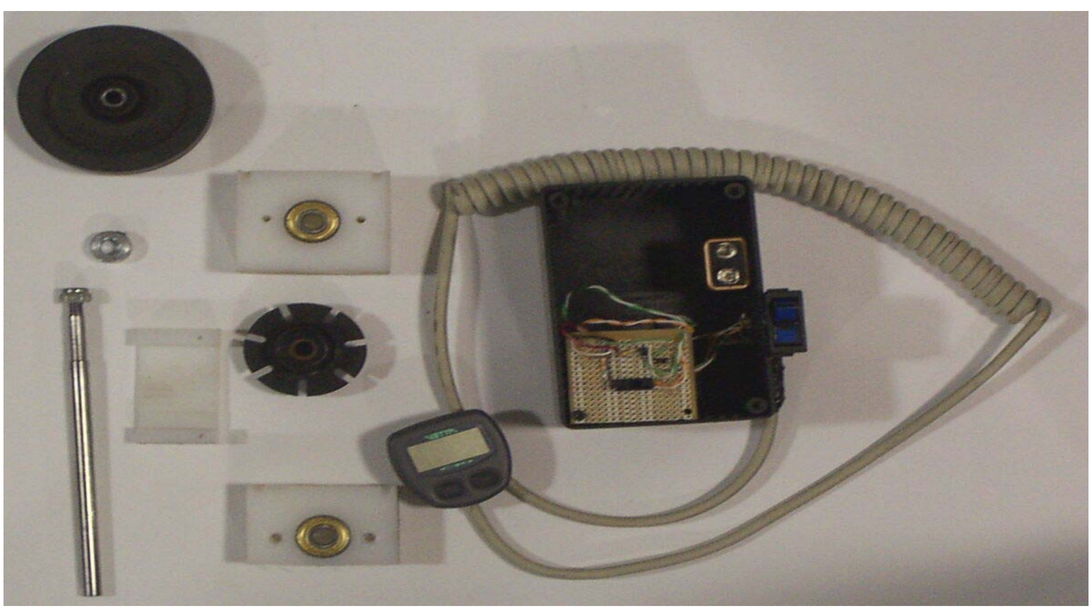

Figure 8: Disassembled Parts

The following steps describe how to assemble the meter:

1. Press the bearings into the UMHW bearing retainers.
2. Attach the bearing retainers to the box with self-taping screws. The larger of the two retainers goes in the end of the box with a hole drilled in it. The smaller retainer goes in the opposite end of the box.
3. Put the wire wheel on the end of the shaft with threads. Place a washer against the wheel and then secure the wheel with a nylock nut. It is easiest to tighten the nut while the shaft is chucked in a lathe.
4. Attach the UMHW circuit board retainer to the inside of the box with two small wood screws.
5. Slide the circuit board into the UMHW retainer.
6. Put the shaft through the hole in the box so that it protrudes enough to place the retaining collar over the end of the shaft inside the box. Then place the sensor wheel in the box so that it is lined up inside the electric eye. While holding the sensor wheel in place slide the shaft through the wheel and into the bearing at the other end of the box.
7. When the shaft is in place tighten the retaining collar to secure the shaft.
8. Put the lid on the box and tighten the four screws.

Figure 9 shows the assembled meter with the lid off.

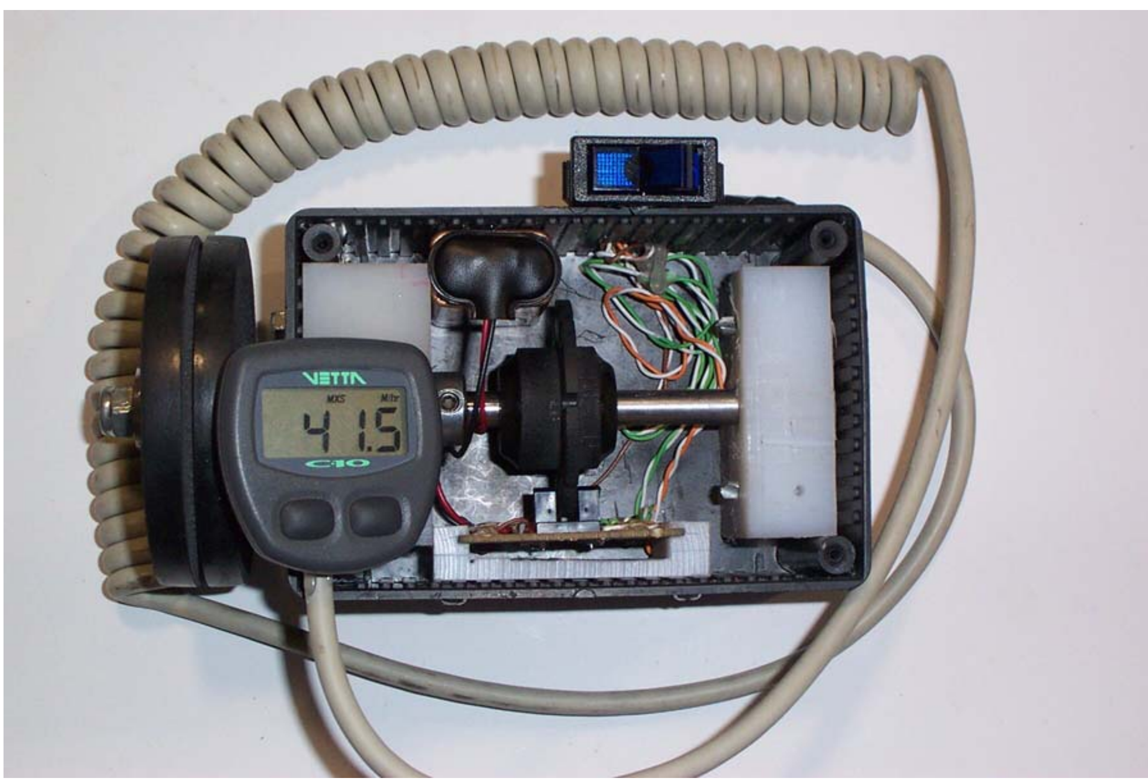

Figure 9: Assembled Meter

3.4 Possible Improvements

Due to time constraints, the cosmetic aspect of the meter was not considered in the manufacturing process. The main focus of the project was to produce a working meter that accurately measures wire feed rates. The following list describes some changes that will improve the look and possibly the durability of the meter.

- Replace the plastic box with one made out of aluminum.
- Make the wire and sensor wheels out of aluminum or UMHW round stock.
- Mount the power switch inside the box and add an l-e-d.
- Make the UMHW bearing retainers smaller.

These changes would produce a more professional looking meter for not too much more money. Unfortunately we ran out of time to make these cosmetic changes as we needed to produce a meter in time to test it for our English report. The next step in the process of producing a meter was testing and assessment.

4.0 TESTING AND ASSESSMENT

4.1 Restating Criteria
As determined earlier, the criteria for the meter were:
- Accuracy
- Portability
- Ease of use
- Reliability
- Low cost

The meter needed to be portable enough to be easily carried and used on a number of different welders. As well, the meter needed to be easy to use and read. The way the meter was calibrated, the display could be read in inches per minute with no further calculations required. It was important that the meter be able to consistently duplicate correct measurements at different feed rates and time intervals. The accuracy of the meter was required to be within 4% of the actual value. Accordingly, a method of testing was developed to determine if the meter was accurate.

4.2 Development of an Accuracy Test
The problem of testing the meter's accuracy required some thought and ingenuity. The test needed to accurately measure a given distance over a given time. The standard for the test must not only be accurate but also consistent over a number of readings. The idea was to find a shaft or wheel whose rpm setting was adjustable. The number of revolutions in a given time was counted. From this count, the linear speed was calculated.

A number of possible alternatives were considered, but the chosen method used the milling machine in the fabrication lab. One of the options on this milling machine is a variable speed, power driven table. The power drive for the table is also connected to the table hand wheel. Using an elastic band as a belt, we connected the meter wheel to the hand wheel. Knowing the diameter of the meter wheel and using the formula for the circumference of a circle, we obtained a linear distance for a given revolution of the hand wheel. Timing a specific number of revolutions resulted in a calculated distance over a given time. This value was compared to the Mech 2002 reading and the meter's accuracy was determined. Figure 10 shows the test setup.

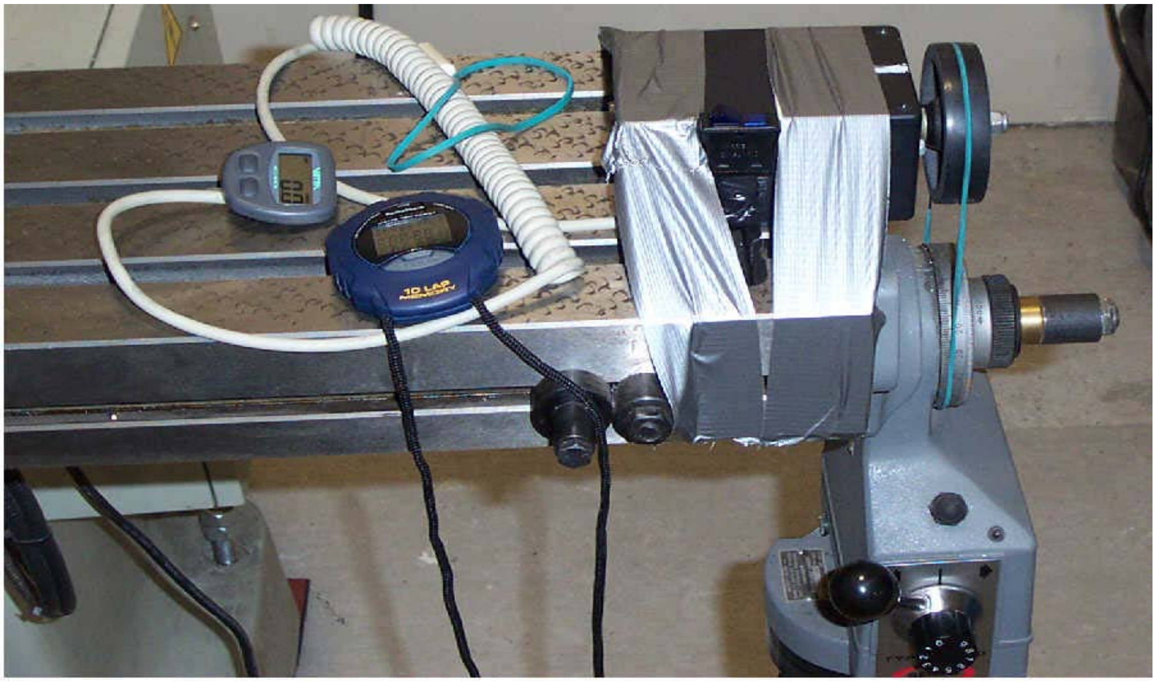

Figure 10: The Test Setup

4.3 Testing Procedure
The meter was secured to the table of the milling machine and an elastic band connected the meter's input wheel to the milling table hand wheel. The test was performed over a range of different speeds and times. The milling machine was turned on and the time to complete five revolutions of the wire wheel was recorded. The speed of the milling table was varied to ensure that the meter would record correctly over its entire range. The next step involved timing ten revolutions at different speeds and recording. Finally twenty revolutions were timed and the results recorded. The readings on the meter were compared to the calculated result of the inches per minute. The following table shows the results of the testing and the percent error between the reading and the calculated results.

The meter was not totally accurate at first and needed to be calibrated, which was done with the variation of wheel sizes available within the programming of the bicycle computer itself. Adjusting the wheel circumference in the computer allowed the meter's accuracy to be fine-tuned.

4.4 Assessment

4.4.1 Results
The result of collaboration and effort is a wire feed rate meter that meets the expected criteria. The tested results, as seen in the appendix B, show that percent errors are within an acceptable level of 4% and that the readings were consistent over a number of different readings. The meter performed consistently over a broad range of rates of speed as noted in Figure 11. The Mech 2002 was also tested on a welder similar to the ones on which it will be used. The wire coming out of the welder was timed and the length of wire measured to give a reading of inches per minute. The accuracy of the results was

consistent with the results from the milling machine rotating hand wheel but more importantly the functionality of the meter was tested on an actual welder and found to be easy to use.

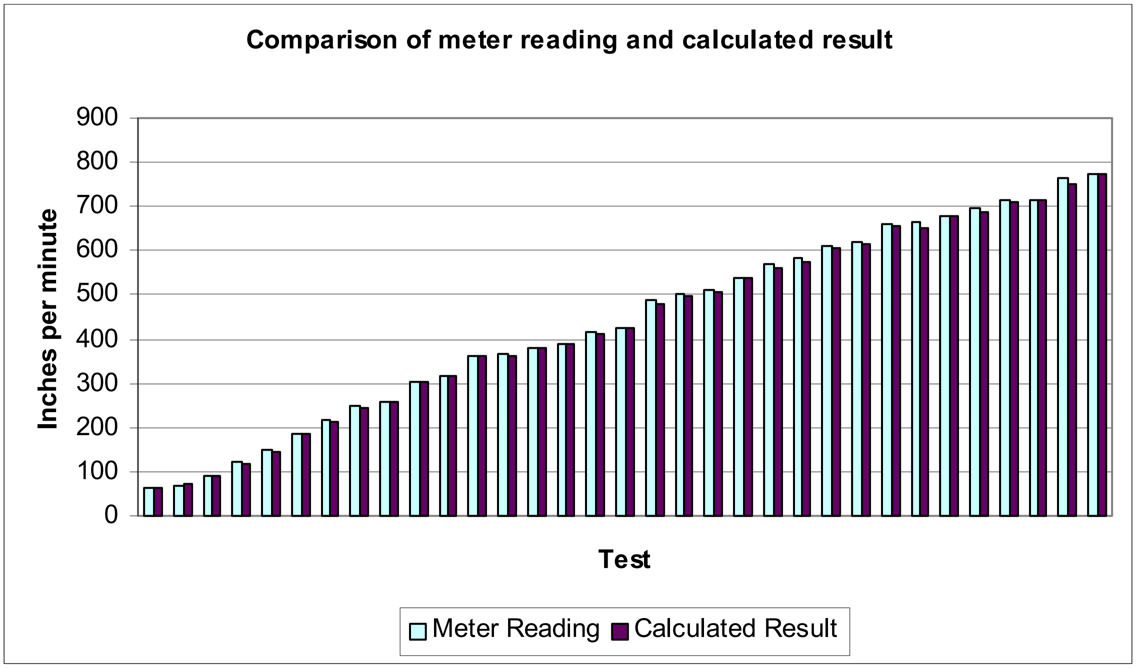

Figure 11: Table of Percent Error at Variable Rates and Trials

4.4.2 Sources of error

Some possible sources of error in the testing of the meter should be noted. Every effort was taken minimize any error in the testing process. One possible area of error may result from not obtaining a precise measurement on the inside diameter of the groove on the meter's input wheel. Great lengths were taken to ensure that this measurement was as accurate as possible. Another area of possible error arises from the elastic used in the testing process. While this elastic ran over both pulleys it was subject to a phenomenon known as belt creep (Nelson, 1986, p. 130). During belt creep the belt riding over a driving pulley is subject to some creeping and therefore actually advances at a speed faster than the pulley is turning. The amount of creep is dependent on the load on the driving pulley. In the case of the meter tests, the load on the pulley was close to negligible and therefore the effect of belt creep would also be negligible.

4.4.3 Limitations

The limitations of the Mech 2002 meter lie with the limitations of the bike computer itself. The minimum and maximum rates that the computer can register are approximately 5.0 to 99.5 kilometers per hour respectively. Thus the range on the meter translates to 50 to 995 inches per minute. Another limitation of the current computer is its resolution. The computer is only accurate to 0.5 kilometer per hour, which from our use of the meter translates to 5 inches per minute. Currently the meter's readings are within the given accuracy criteria. However, at slower rates the five inches per minute difference becomes a greater degree of error. This difference can be seen by the trend line of figure 12. Solving this problem requires a bike computer that has a greater degree of accuracy. A computer able to measure to the nearest tenth of a kilometer per hour would improve the accuracy of the meter to one inch per minute. At the time of our testing, such a computer was purchased to increase the accuracy of the meter. However, the new computer required a higher input signal, which meant a redesign of the electronic portion of the meter. Time constraints forced the testing to continue with the less accurate computer, but it should be noted that the new computer could be substituted at a later date to increase the meter's accuracy. Also, time constraints have not allowed the long term reliability of the meter to be determined. However, because the meter's construction is simple and rugged, reliability should not be a problem and this parameter can best be tested through actual use.

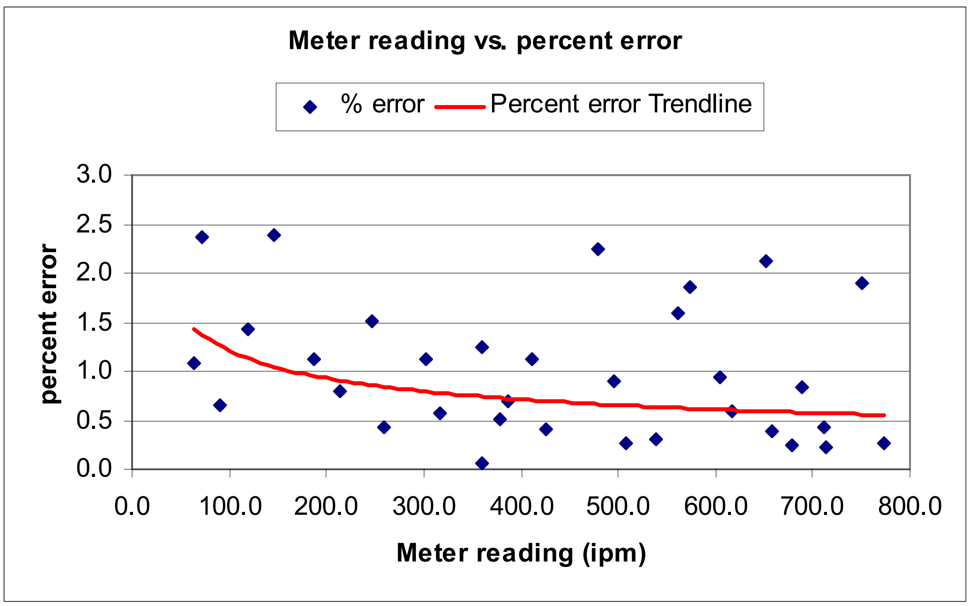

Figure 12: Meter Reading Vs. Percent Error

5.0 CONCLUSIONS AND RECOMMENDATIONS

While the meter performs within the given criteria of accurate to within 4%, the ability to increase the meter's accuracy remains a viable option. This greater degree of accuracy would ensure that the meter operates well within the established criteria. Although the addition of the new bike computer would mean a redesign of the electronics, the payoff would be a meter that is accurate to one inch per minute. A greater degree of accuracy would instill more confidence in the meter from the end user. Other changes to be made to the meter would be mainly for cosmetic reasons. Due to time constraints the cosmetic aspect of the meter was not considered in the manufacturing process. The main focus of the project was to produce a working meter that suits the need of accurately reading wire feed rates. The following list describes some changes that will improve the accuracy, appearance, and possibly the durability of the meter.

- Replace computer with higher resolution computer.
- Replace the plastic box with one made out of aluminum.
- Make the input and sensor wheels out of aluminum or UHMW round stock.
- Mount the power switch inside the box and add an l-e-d.
- Make the UHMW bearing retainers smaller.

These changes would produce a more professional looking meter for not too much more money. Overall the meter, as is, meets the required criteria and is ready for use.

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APPENDIX A: CALCULATION OF THE NUMBER OF SLOTS IN THE SESOR WHEEL

The bicycle speedometer reading in kilometers per hour (kph) must be read directly as a welding wire feed rate in inches per minute (ipm). For example, 30 kph would read as 300 ipm. In effect, the speedometer must be 'fooled' into 'thinking' that the meter wheel, being spun by the wire traveling at 300ipm, is rotating at the same angular speed as the bike wheel traveling at 30 kph. The meter wheel turns much slower than the bike wheel and the number of slots in the sensor wheel determines how fast the bike computer 'thinks' the meter wheel is rotating. If there are two slots in the sensor wheel, the computer 'thinks' the meter wheel is rotating twice as fast as it actually is- three slots, three times as fast, et cetera. Therefore the angular speed of each wheel, at its respective speed, needs to be calculated. Dividing the angular speed of the bike wheel by the angular speed of the meter wheel results in the number of slots required in the sensor wheel. These calculations are shown below.

Angular velocity of a 24 inch bike wheel at 30 kph (v_b):

$$24 \text{ inches} \times \frac{2.54 \text{ cm}}{\text{inch}} \times \frac{1 \text{ meter}}{100 \text{ cm}} = .6096 \text{ meters}$$

$$V_b = 30\text{kph} \times \frac{1000 \text{ meters}}{\text{kilometer}} \times \frac{1 \text{ hour}}{3600 \text{ sec}} \times \frac{2p \text{ radians}}{p\,(.6069 \text{ meters})} = 27.463 \frac{\text{rad}}{\text{sec}}$$

Angular velocity of the 2.725* inch meter wheel at 300 ipm (v_m):

* diameter at the bottom of the groove in the meter wheel.

$$V_m = 300\text{ipm} \times \frac{1 \text{ min.}}{60 \text{ sec.}} \times \frac{2p \text{ radians}}{p\,(2.725 \text{ inches})} = 3.6697 \frac{\text{rad}}{\text{sec}}$$

Number of slots required (N):

$$N = V_b / V_m = \frac{27.463 \text{ rad/s}}{3.3397 \text{ rad/s}} = 7.48 \text{ slots}$$

Obviously there cannot be a fraction of a slot, therefore the nearest whole number of 7 was chosen. The calculation was then run in reverse to determine the exact diameter of the bike wheel to be input to the speedometer in order that the readings coincide.

$V_b = N \times V_m = 7 \times 3.6697\text{rad/s} = 25.688\text{rad/s}$

$$25.688\frac{\text{rad}}{\text{s}} \times \frac{\text{p(D)}}{\text{2prad}} \times \frac{\text{3600s}}{\text{hour}} \times \frac{\text{1 kilometer}}{\text{1000 meters}} = 30 \text{ kph}$$

where D is the bike wheel diameter in meters.

Solving, D = .6488 meters

The bike computer input is the circumference of the wheel (C) in millimeters.

$$C = \text{(p) .6488 meters} \times \frac{\text{1000 mm}}{\text{meter}} = 2038 \text{ mm}$$

With seven slots cut in the sensor disk, a circumference of 2038mm input to the bicycle computer will allow a direct reading of inches per minute if the decimal is ignored.

APPENDIX B: TEST RESULTS

Table 1: Recorded Data

METER READING		REVOLUTIONS		TIME	CALCULATED RESULT	% ERROR
(INCHES/MIN)				(SEC)	(INCHES/MIN)	
65		5		41.75	64.3	1.0
70		5		37.46	71.7	2.4
90		5		29.65	90.6	0.7
120		5		22.71	118.3	1.5
150		5		18.34	146.5	2.4
185		10		28.71	187.1	1.1
215		10		25.18	213.3	0.8
250		10		21.81	246.3	1.5
260		10		20.75	258.9	0.4
305		10		17.81	301.6	1.1
315		10		16.96	316.8	0.6
360		10		14.93	359.8	0.0
365		10		14.9	360.5	1.2
380		10		14.21	378.1	0.5
390		10		13.87	387.3	0.7
415		10		13.09	410.4	1.1
425		10		12.59	426.7	0.4
490		10		11.21	479.2	2.2
500		10		10.84	495.6	0.9
510		20		21.12	508.7	0.3
540		20		19.96	538.3	0.3
570		20		19.15	561.1	1.6
585		20		18.71	574.3	1.9
610		20		17.78	604.3	0.9
620		20		17.43	616.4	0.6
660		20		16.34	657.5	0.4
665		20		16.5	651.2	2.1
680		20		15.84	678.3	0.3
695		20		15.59	689.2	0.8
715		20		15.09	712.0	0.4
715		20		15.06	713.4	0.2
765		20		14.31	750.8	1.9
775		20		13.9	773.0	0.3