PHAOSTRON INSTRUMENT & ELECTRONIC CO.

151 PASADENA AVE. ■ SOUTH PASADENA ■ CALIFORNIA 91030 ■ (213) 255-1471 ■ TWX 910-321-4134

THIRD DEVELOPMENT REPORT
FOR
1% ACCURACY, 40 and 100 MICROAMPERE RUGGEDIZED TAUT BAND PANEL METERS (5-1/2" x 4-1/2")

THIS REPORT COVERS THE PERIOD 5-1-68 to 7-31-68

Phaostron Instrument and Electronic Company
151 Pasadena Avenue
South Pasadena, California 91030

NAVAL ELECTRONIC SYSTEMS COMMAND, NAVELEX 05143B

CONTRACT NUMBER - N00024-67-C-1190

MODS-P001, P002, P003 and MODS-A001, A002

PROJECT SERIAL NO. XF02102 TASK 9633

AUGUST 1968

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Serial No. 53

35

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ABSTRACT

A successful high shock test on the first model completed its testing program. Upon its completion, nine units were assembled for a complete specification checkout.

Theoretical and experimental studies were conducted to determine the characteristics of four taut bands. Three of these bands were selected on the basis of these studies for the nine units.

Theoretical studies of terminal resistance compensation indicated that a deviation of nearly 1% can be achieved.

Two forms of shielding -- a nickel mesh and conducting glass -- will be tested for shielding effectiveness against electromagnetic interference.

The testing program for the nine units began at the close of the quarter.

PART I

PURPOSE

To develop a group of precision taut band meters, ranges 40 microamps and 100 microamps, for incorporation into multimeter equipment. The units must pass all the environmental and other requirements of MIL-M-10304C except that the performance and accuracy of the units before and after the tests are generally required to be upgraded by a factor of two. Additional objectives are improved terminal resistance compensation and radio frequency interference studies.

Specific requirements comparison table:

DESCRIPTION	MIL-M-10304C/17C	IMPROVED OBJECTIVE
Position influence	± 2%	± 1% of full scale
Linearity accuracy	Not Applicable	± 1/2% " "
Initial accuracy	± 2%	± 1% " "
Exp. to extreme temps.	± 10%	± 2% " "
Momentary overload	± 2%	± 0% " "
Rotational influence	Not Applicable	± 1% " "
Vibration	± 5%	± 2% " "
Random drop	± 5%	± 2% " "
Shock	± 5%	± 2% " "

GENERAL FACTUAL DATA

IDENTIFICATION OF PERSONNEL:

During this quarter the personnel listed below charged time to the project as shown.

Personnel	Total Hours
C. Candelaria	160
J. Gonzales	200
E. Frastaci	146
J. Coakley	280
K. Rusk	157
G. Bandas	200
N. Logan	64
A. Sterner	38
J. Bowman	270
W. Faiss	127.6
F. Bowman	200
F. Formentini	169.9
R. Briendenstein	47.2
V. Rosenquist	11.2
K. Love	105.9
K. Palmer	112.6
G. Shock	80.5
G. Wynn	121.9
S. Zambrano	136
R. Salustro	6
G. Castro	48
S. Scofield	90
R. Gonzales	90
G. Allstadt	22.7
H. McWilliams	36.6
TOTAL	2,921.1

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   Torsion Devices.
   British Scientific Instrument Research Assoc., Kent. England.

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   Portable Bifilar Electrical Meters. (Brochure)

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   Taut Band Suspension Type Meters. (Brochure)

8. LAWS F. A., 1938.
   Electrical Measurements. New York
   McGraw Hill.

9. SIGMUND COHN CORP., 1963. New York
   Platinum Alloys. (Brochure)

10. THOMANDER V. S., 1963.
    Filar Suspended Instrument Movement.
    U.S. Patent 3,111,623.

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    Switchboard & Portable Instruments.
    Catalog Section 43-240, 43-150.

MEASUREMENT PROCEDURES:

The following equipment is part of that maintained in the Phaostron engineering test laboratory and is used for calibrating and testing. All equipment is certified to MIL-C-45662A Calibrating System requirements.

Wheatstone Bridge., Leeds & Northrup. Model 5305, Serial 1128
1 ohm - 1 megohm. 1% accuracy. 90 day check.

Optical Projector., Kodak. Model 30KCP
30 inch. .0002" accuracy. Yearly check.

Vibrator., M & B. Model T51M, Serial 1742
5 - 3000 Hz. 1200 lb. 30 day check.

Random Drop Machine., U.S. Government #2. Per MIL-STD-202. Method 203. Serial 1718.

Heat Chamber., Phaostron. Serial 1704
25°C/300°C. 1° accuracy. 180 day check

Cold Chamber., Phaostron. Serial 1705
25°C/-70°C. 1° accuracy. 180 day check.

Humidity Chamber., Phaostron. Serial 1706
25°C/70°C. 1° accuracy. 180 day check.

Dielectric Tester., Phaostron. Serial 1310
0/5000 VAC. 2.5% accuracy. 30 day check.

Precision Power Supply., John Fluke Mod. 351A, Serial 1839
1 uA/100 mA.D.C., 05% accuracy. 30 day check.

Megger., Biddle. Model 4. Serial 1744
0/50 megohms. 2% accuracy. Yearly check.

Vacuum Pump., Cenco. Serial 1179
0/30 inches. 2% accuracy. Yearly check.

Impact Tester., Phaostron. Serial 1040

Hot Water Tank., Pricilla. Serial 1022
25°C/100°C. 1° accuracy. 180 day check.

Cold Water Tank., Pricilla. Serial 1162
25°C/0°C. 1° accuracy. 180 day check.

Gaussmeter., F. W. Bell. Model 110. Serial 28166
1 gauss/30 K gauss. 2% accuracy. Before use.

Balance., Roller Smith. Serial 1080
0/500 mG. 1/2% accuracy.

DETAIL FACTUAL DATA

INTRODUCTION:

This quarter was devoted to a number of theoretical studies and experimental testing programs. Special emphasis was placed on the characteristics of taut bands, the problems involved in temperature compensation and electromagnetic interference, and the design difficulties encountered with the first model.

The testing program for the first model was completed. Upon its completion, nine units were built for a complete specification checkout and review.

SELECTION OF MATERIALS:

Movement Housing (4) & Bridge (3)

Free turning brass rod, Alloy #271, half hard drawn. A non-ferrous material is necessary for these parts as they are in contact with the magnet.

Coil Form (1)

Aluminum alloy #6061-T6. Selected for lightness as it is part of the moving element, and high yield and tensile strengths when heat treated. After forming, the bobbin is anodized which provides insulation of the winding surface (115VAC), adds rigidity to the coil form and provides a corrosion resistant surface. A useful reference is "Guidelines for the Design of Moving Coil Forms" by Judson A. Smith Co., Boyertown, Pennsylvania 19512.

Coil Tie Points - Band Location Lug (6)

Beryllium copper alloy #25. Half hard, has to be springy yet soft enough to allow bands to bed down in locating groove.

Coil Bases (7)

Aluminum #2024 - T4. Finish 32 ST. Screw machine part. Lightness required, also has to be staked to hold band locating lugs.

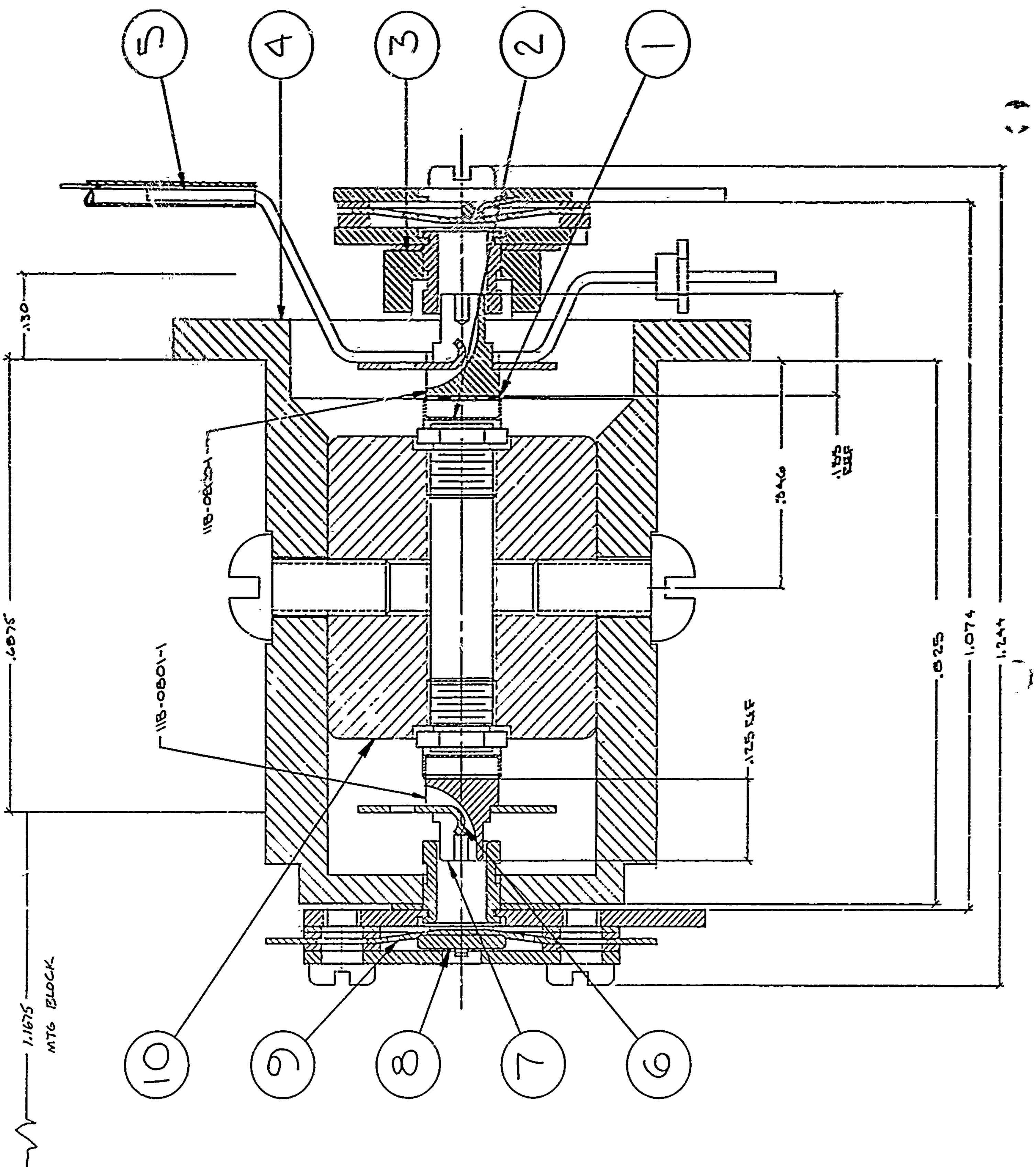

1
2
3
4
5
6
7
8
9
10
.130
.6875
1.1675
MTG BLOCK
11B-0801-1
11B-0801-1
.125 REF
.346
.155 REF
.825
1.074
1.244

Figure 1

Spring Shaft (8)

Phosphor bronze, spring temper, polished lapped surface equivalent to 4L or better so that taut band ligament has a smooth surface to bend over. Shaft is spot welded to end spring.

End Springs (9)

Phosphor bronze, spring temper, selected for machinability and solderability and weldability to spring shaft.

Movement Core (10)

Cold rolled acid Bessemer steel #B-1113. An excellent free cutting low carbon steel. It has a magnetic capacity of about 9,000 gauss which is more than double the gauss in the coil gap.

Magnetic Pole & Housing

Cold rolled acid Bessemer steel #B-1113

Case & Bezel

Aluminum alloy #2024-T3. Selected for lightness and good machinability. Anodized per Mil-A-8625 Type 11 and painted for corrosion resistance.

Magnet

Alnico 5 DG. Has the highest peak energy product (Bd Hd) Max x 10^6 = 6.25, of any of the readily available magnetic materials. Alnico 9 which has a peak energy of 10.0 is only available in limited production from one domestic source and costs five to ten times as much as Alnico 5 DG.

Movement Retaining Bracket

Has to be non-magnetic. Aluminum alloy 6061-T6 selected for strength and lightness.

Terminal Bushings

G10 Epoxy Rod per Mil-P-18177 selected for mechanical strength and insolation properties.

Terminals & Hardware

Free turning brass, alloy #271, half hard drawn selected for machinability, solderability, and electrical conductivity.

Zero Adjust Button

Needs to be an insulator for safety purposes. To be tough to withstand the abuse of screwdriver bits and environmental pressures. Material - black nylon.

Epoxy

Eccobond #45 is a controlled flexibility epoxide adhesive. The flexibility is controlled by the amount of catalyst #15. A flexible formulation is used for impregnating the coil winding and adhering to the coil bobbin. A semi-rigid formulation is used to cement the coil to the two termination assemblies. Has a pot life of at least three hours at room temperature, or will take a rapid cure of 30 minutes at 160° F or 15 minutes at 220°F.

Gaskets for Window, Terminals and Zero Button

As these parts are in contact with polycarbonate plastic, the compatability of the rubber with the plastic must be checked. Incompatability shows by craze lines developing at the contact surface of the polycarbonate due to solvents being extracted by the rubber especially under conditions of pressure and elevated temperature.

The rubber suppliers are somewhat reluctant to give the formulation of particular mixes but the following have been checked and approved by actual tests:

West American-Compound #440

Parker "O" Ring - Compound C401-7, C551-7, C521-7

Reeves Rubber - Compound P1 and P1A

The test is quite simple. Sample strips of polycarbonate 5" x 1/2" x 1/8" are bent like a bow with a piece of copper wire taking the place of a string. The amount of bend is about 1". This causes the outside surface of the strip to be under considerable tension. The rubber sample is then wrapped around the plastic at the mid point and subjected to 16 hours at 90°C. A control plastic without rubber is also used during the heat test. It should show no signs of crazing.

Mounting Block

Machined from polycarbonate plastic. An insulation material is required to isolate the movement from the case. Polycarbonate can be considered semi-rigid and withstands the stress of high shock without cracking or distorting.

Pointer

Beryllium copper, hard drawn wire, alloy #25, heat treated at 600°F for 2 hours. Flexibility without any permanent change is required for this part as the pointer undergoes considerable distortion during vibration, random drop and high shock tests.

Pointer Guide Tube

Helps limit the deflection of the pointer wire. Aluminum alloy #6061-T6 used for tensile strength and lightness.

Window

Clear polycarbonate sheet. While this plastic is not as optically clear as the acrylics and styrenes, it is the only material that withstands the temperature immersion and high temperature tests without bowing, crazing, or distortion. Tempered glass could be used, but it would complicate the design by requiring cushioning wherever it comes in contact with the case or bezel. The shape would be expensive to produce and the thickness would have to be increased to pass the "impact test for windows".

Pointer Cross Balance(5)

Aluminum alloy #7075 selected because of lightness. It possesses the maximum mechanical properties for a part to which the pointer and balance weights are attached and which must not permanently distort during vibration, random drop and high shock tests.

Dial Pan

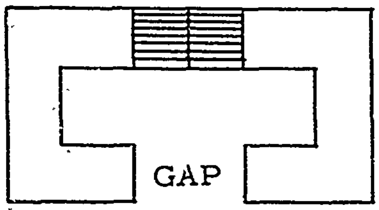
Is made of paper base epoxy Mil-P-22324A. For insulation purposes between the case and the movement pointer.

Dial Mirror

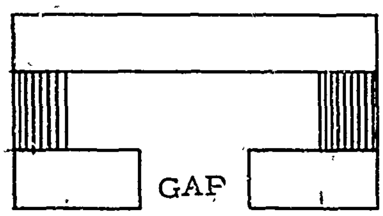
Pressure sensitive metalized mylar.

SELECTION FOR MAGNET DESIGN:

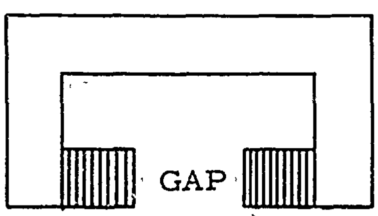
a.



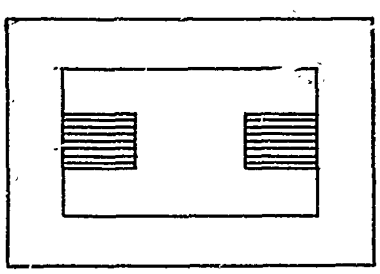
b.



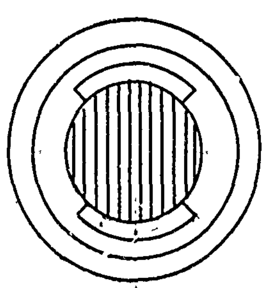
c.



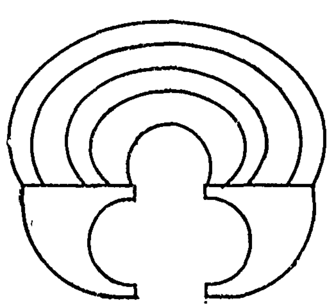
d.



e.



f.



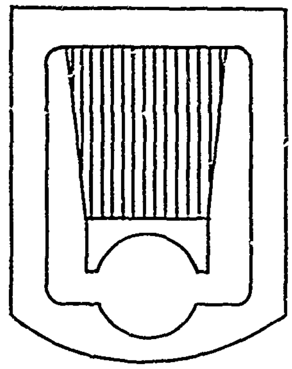
References from magnet data emphasize the importance of placing the permanent magnet as near the air gap as practical. This will reduce leakage flux and achieve more efficient use of the magnet.

In magnetic circuits a, b and c with uniform volumn magnet(s) in each case, the flux in the gap if taken as 100 for c, would be about 76 for b and about 46 for a.

It was found necessary to lower the movement center in relation to the inside edge of the case to obtain the maximum pointer length and scale arc possible. This requirement meant that a design such as d, could not be used.

A core magnet approach was discarded when preliminary investigation showed that increasing the diameter to achieve the same restoring torque would increase the weight of the coil by about 50% and the resistance would be increased by a similar amount.

While a brute force approach may be used, it follows that the efficiency per unit volumn of magnet will be low. The stray leakage flux presents a problem because of the necessity for shielding so that iron components such as transformers or steel tools do not affect the accuracy of the meter. Providing an adequate shield on all sides of the magnet will in turn shunt the flux in the magnet to a lower level.



The center bar magnet design, places the magnet close to the air gap, allows the movement center to be placed low down on the vertical centerline and is self-shielded by reason of the surrounding iron ring. The flux in the air gap is roughly proportional to the length of the magnet. While the inside case diameter would permit an increase of 50% in length it is not considered necessary.

SUGGESTION FOR CASE MODIFICATION:

A considerable reduction in the size of the case barrel is possible. The full size sectional view in Figure 1a shows the relation of the magnet to the rear of the case. At least 3/4" as shown by the dotted line could be removed without affecting the performance of the meter or crowding any internal components.

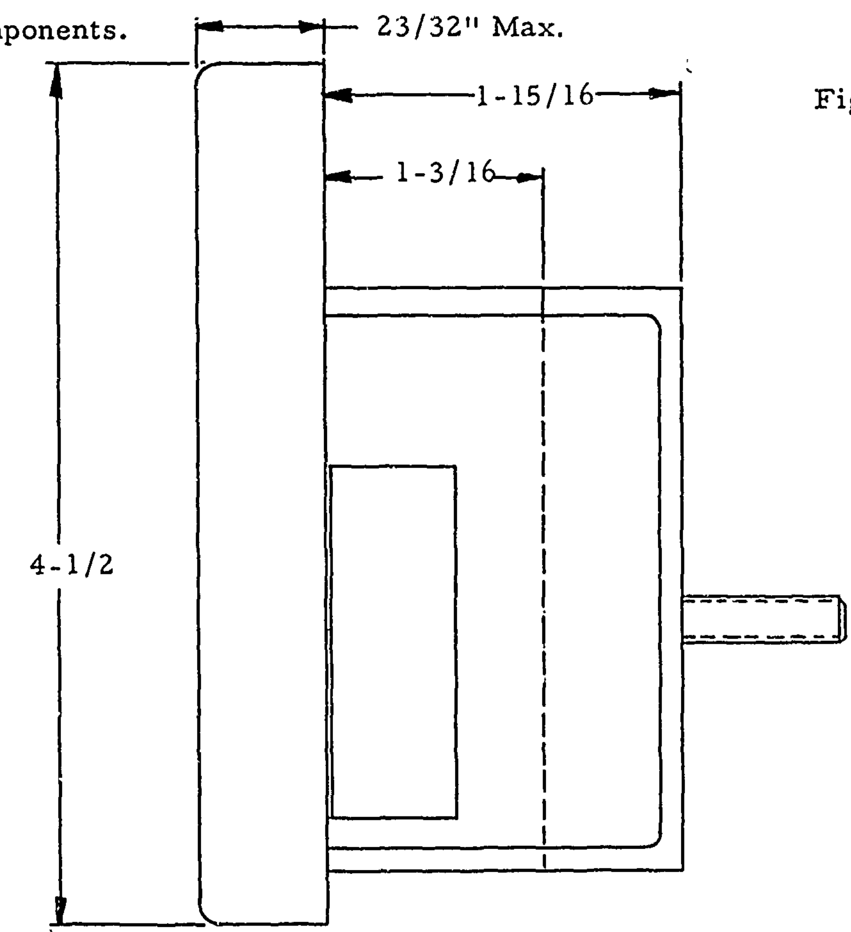


Figure 1a

TAUT BAND:

The taut band must have certain physical properties in order for it to be applicable to meter designs. In the meter it supports the moving element, supplies the returning torque to the coil, and it also acts as the electrical conductors leading to and from the coil. In the case of a shock proof meter, the band should have a large tensile strength.

At the same time the band should have a moderate torsional modulus. It should be a good conductor, and nonmagnetic. Finally, to maintain better stability, it should be corrosion resistant, have a minimal elastic after effect and have a small hysteresis.

The most important characteristic of the band is the torque it developes when twisted. The theoretical value of the torque is given by:

$$M = \frac{G \theta b h^3 f(u)}{L} + \frac{P(b^2 + h^2)\theta}{12 L} + \frac{E b^5 h \theta^3}{360 L^3}$$

M = Torsional moment (gmcm for a torsional angle θ).

θ = Torsional angle in radians

G = Torsional modulus (gm/cm^2)

E = Young's modulus (gm/cm^2)

P = Tensile load along the longitudinal axis (gm)

L = Length of the taut band (cm)

b = Width of the taut band (cm)

h = Thickness of the band (cm)

u = Aspect ratio (u = b/h)

f(u) = A geometrical constant which takes the values given in Table I

TABLE I

u	1	4	6	8	10	∞
f(u)	0.1410	0.2808	0.2985	0.3072	0.3124	0.333

TABLE II

Alloy	Resistivity In Ω CM	Tensile Str. In GM/CM^2	Young's Mod. In GM/CM^2	Modulus of Torsion in GM/CM^2	% Elongation
CARL HAAS					
CH 31	9.1×10^{-5}	270×10^5	2150×10^6	860×10^6	1.40
CH 33	8.3	230	1730	690	1.4
CH 51	2.9	170	1960	785	1.5
CH 54	3.3	230	1170	470	1.60
CH 53	3.64	260	2550	1020	2.6
CH 73	2.9	175	1130	453	2.5
CH 11	1.7	150	1120	447	1.8
CH 13	0.30	110	1070	427	1.5
SIGMUND COHN					
#479	6.65×10^{-5}	176	1760×10^6	704×10^6	2
#851	2.99	176	1760	704	2
Pt-10% Ni	3.08	161	1760	704	2

TABLE IIA

ALLOYS

CH 31	Nivaflex - Iron - Cobalt - Nickel - Chromium
CH 54	Platinum - Silver 90 - 10
CH 13	Copper - Magnesium - Bronze
Pt-10% Ni	Platinum - Nickel 90 - 10

In the equation for the torsional moment, the first term represents the torque due to the shear stresses. The second represents the torque due to the axial force. And the third is the torque due to longitudinal stresses. The torsional moment is nearly a linear function of twist. Only the longitudinal stresses give rise to a non-linear component of torque and this component is usually small enough to be neglected. The torsional moment is also directly proportional to the torsional modulus and indirectly proportional to the length. In order to keep the torque at a moderate level, the torsional modulus should be as small as is feasible when considering bands with large tensile strengths. Unfortunately, the length of the band must be kept small to reduce the sag of the moving coil.

The torsional moment is also expressed in terms of the aspect ratio and the cross sectional area.

$$M = \frac{GA^2\theta}{uL} + \frac{PA(u^2+1)\theta}{12\,uL} + \frac{A^3u^2E\theta^3}{360\,L^3}$$

A is the cross sectional area. In the case of the taut band meter, the first term of the expression is the dominating term of the torque. Thus, in order to keep the torque small, "u" should be large and "A" should be small. A second reason for having a large aspect ratio is that for a given torque a band of larger cross sectional area can be used and thus it will have a relatively large shearing point.

There are a large number of different alloys which are commercially available. Table II lists the physical properties for Carl Haas and Sigmund Cohn taut bands. Table III lists the theoretical values of the components of torque along with the total torque for the bands. The values in Table III are for two 5mm bands .00048" x .0048" with an axial load of 50 gm and a twist of 90^{o}. These values are similar to the conditions in taut band meters.

The taut bands are intrisically non-linear. The non-linear component of the torsional moment is expected to be as high as 0.3% for a twist of 90^{o}. This non-linearity limits the ultimate linearity of the taut band meter.

TABLE III

Alloy	Torque Due To Shear Stress mgcm/90°	Torque Due To Axial Force mgcm/90°	Torque Due To Longitudinal Stress mgcm/90°	Total Torque mgcm/90°	Torque For 2 5 mm Bands	% Non-Linear
CARL HAAS						
CH 31	18.76	0.982	.0605	19.80	39.60	0.30
CH 33	15.04	0.982	.0487	16.07	32.14	0.30
CH 51	17.12	0.982	.0552	18.16	36.32	0.30
CH 54	10.24	0.982	.0330	11.25	22.56	0.29
CH 53	22.24	0.982	.0718	23.29	46.58	0.31
CH 73	9.88	0.982	.0318	10.89	21.78	0.29
CH 11	9.76	0.982	.0315	10.77	21.54	0.29
CH 13	9.28	0.982	.0301	10.29	20.58	0.29
SIGMUND COHN						
#479	15.36	0.982	.0498	16.39	32.78	0.30
#851	15.36	0.982	.0498	16.39	32.78	0.30
Pt-10% Ni	15.36	0.982	.0498	16.39	32.78	0.30

EVALUATION OF THE TAUT BAND:

Four taut bands were selected for testing - Carl Haas bands of alloys: CH 31, CH 54, and CH 13; and Sigmund Cohn's Pt-10% Ni band. The bands were selected on the basis of minimum after effect, maximum tensile strength, minimum resistivity, and compromise characteristics. They were used in taut band meters with 90° scales.

Eight taut band meters were built. Four of them incorporated moving elements suspended by unsprung taut bands (i.e. the end springs were constrained) to study the characteristics of the band alone. The other four meters were normal ruggedized meters which were used to study the characteristics of the combined taut band and suspension springs. The first and perhaps the most important part of the evaluation was measuring the torque of the bands. It was measured by calculating the torque on the energized coil in the permanent magnetic field of the meter. It was also measured by placing a known weight on the balanced pointer of the meter and observing the moment arm required for a deflection of 90°. The values of torque obtained by the two methods were almost identical. These values were used to determine the coil windings for the nine meters for testing.

The linearity of both the taut bands and the taut bands combined with the suspension springs was checked by measuring the amount of current needed for the coil to traverse a 9° deflection at a position in the magnetic field well away from the regions of field fringe effects. The current interval was measured for different angles of twist in the band.

The after effect of the bands was measured by deflecting the coils by 90° for periods greater than thirty minutes and then removing the current slowly. The difference in zero positions of the meter 20 seconds after the current was removed represented the after effect of the band.

The hysteresis of the taut band was measured by slowly increasing the current applied to the meter and taking measurements at each cardinal point until the full scale reading was taken. Then the current was slowly decreased and measurements at each cardinal point were taken. The differences between the two sets of readings represented the hysteresis effect.

The results obtained in those evaluations are given in Table IV. Since the results for the unsprung taut band and those for the suspended taut band are very close, it is likely that the suspension springs do not contribute greatly to the unwanted effects of the meter.

TABLE IV

VALUES FOR UNSPRUNG TAUT BANDS

Alloy	Linearity	After Effect	Hysteresis
CH 31	0.6%	0%	0.05%
CH 54	0.4*	0	0.1
CH 13	0.4*	1	1.1
Pt-10% Ni	0.5	0	0.16

VALUES FOR SUSPENDED TAUT BANDS

Alloy	Torque In mgcm	Linearity Error	After Effect	Hysteresis
CH 31	37	0.6%	0%	0.2%
CH 54	27	0.6	0	0.3
CH 13	18	0.4	1	0.8
Pt-10% Ni	33	0.5	0	0.16

* For 80° angle of twist

The deviation from linearity of the taut bands is as high as 0.6%. This additional error in linearity over the expected value of 0.3% is attributed to changes in the band due to handling and also the deviation in the length of the bands from 5mm. The linearity of these eight meters was in excess of 2%. The additional error was due to the fringing effects of the magnetic field near the zero and full scale coil position and also due to the small deviations of the coil from a central position in the magnetic field.

It is interesting to note that the deviation of the current increments between scale divisions from their mean may be as small as 0.2%. However, the error in linearity is accumulative. The readings taken for the current increments for small angles of twist are very close to the mean value. On the other hand, the large deviations are found near full scale deflections. This is expected from the fact that the non-linear component of the band increases as θ^3. Table V illustrates this point.

TABLE V

Current Increments	Deviation From Mean 20.0 uA	Theoretical Values Of Current At Scale Divisions	Actual Values	Deviation From Linearity
19.4	-0.6	20.0	19.4	-0.6
19.8	-0.2	40.0	39.2	-0.8
19.9	-0.1	59.9	59.1	-0.8
19.9	-0.1	79.9	79.0	-0.9
19.9	-0.1	99.9	98.9	-1.0
20.0	0	119.9	118.9	-1.0
19.9	-0.1	139.9	138.8	-1.1
20.3	+0.3	159.8	159.1	-0.7
20.1	+0.1	179.8	179.2	-0.6
20.6	+0.6	199.8	199.8	--

Maximum deviation of current increments from 20.0 uA is 0.3%.

Maximum deviation from linearity is 0.55%.

COIL SAG:

In order to maintain acc ate readings, the coil sag should be minimized. This is accomplished by putting tension on the ligaments. The amount of sag is expected to be:

$$S = \frac{WL}{2P}$$

W is the weight of the moving element (750 mg).

L is the length of the supporting taut band (0.5 cm),

P is the tension in the band (40 gm).

From the formula, in order to limit the sag to 0.005 cm the tension in the ligaments must be fifty times the weight of the moving element.

The tension is applied to the taut band by the suspension springs. The constants for these springs were found to be about 1180 gmcm. The springs are normally displaced .014" giving about 40 gm tension on each of the 5mm bands. The weight of the moving elements was found to be near 750 mg. Further attempts will be made to increase the tension.

CENTERING:

The coil should be accurately centered in the magnetic gap. Any deviation of the coil from the central position places it in a different magnetic field which then gives rise to a different current torque ratio. In turn the deviation of the current torque ratio from a constant value is a cause for non-linearity and inaccuracy.

The coil is centered in the magnetic gap when the taut band is centered to the coil. This is accomplished by tie point fixtures which are centered on each end of the coil. Figure 2 is an illustration of the fixture.

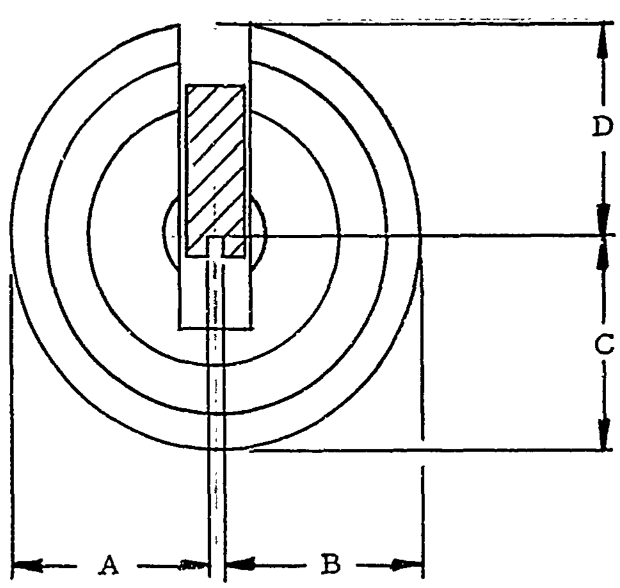


Fig. 2

The band locating lugs were checked for centering with a forty power microscope which was fitted with a calibrated reticle in the eye piece. Distances A, B, C, and D, in Figure II were measured and the values are tabulated in Table VI.

TABLE VI

Part	A in Inches	B in Inches	C in Inches	D in Inches
1	.033	.036	.039	.031
2	.032	.034	.038	.032
3	.033	.033	.033	.036
4	.031	.033	.037	.032
5	.034	.032	.034	.034

It is evident that the locating lug is not accurately centered. In the case of future meters, the locating lugs will be checked and those with accurate centering will be selected for the assemblies.

TEMPERATURE COMPENSATION:

This meter is required to maintain a voltage drop within 2% of the 25°C value over temperatures ranging from -28°C to 65°C. The aim of this program is to achieve a deviation of 1% over the temperature range.

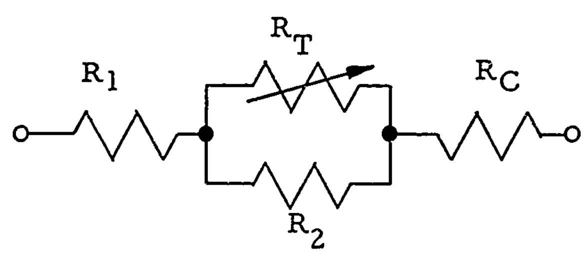
The compensation network includes a thermistor in parallel with a shunt resistor. Thermistors are readily available from General Electric and Keystone Carbon Company. General Electric has four grades of thermistors -- "Grade #2" has been found to be the best suited for the temperature compensation of copper. Keystone, on the other hand, has a greater selection of materials which covers a large range of temperature coefficients of resistance to choose from.

The shunt resistors should maintain a resistance which is independent of temperature. For this reason wire wound resistors of manganin wire were selected.

An additional manganin wire wound resistor is placed in series with the coil and compensation network to increase the overall resistance of the meter to the desired value. This series resistor also helps to improve the stability of the meter resistance over the temperature range.

Theoretical values for the thermistors, shunt resistors, and series resistors were calculated for the General Electric "Grade #2" thermistors. The compensation was calculated for two coils incorporated in the 100 uA test samples. The values obtained are given in Table VII. In addition to these values, Keystone recommended the thermistors and shunt resistors listed in Table VIII.

TABLE VII



R_1 - Series Resistor

R_2 - Shunt Resistor

R_T - Thermistor

R_C - Coil Resistance

VALUES OF G.E. "GRADE #2" THERMISTORS
FOR 1000 OHM, 100 uA METER

Resistor	R_C = 468Ω	R_C = 617Ω
R_1	436Ω	257Ω
R_2	217Ω	286Ω
R_T @ 25°C	150Ω	200Ω

EXPECTED DEVIATION:

For 468 Ω Coil Network - 0.92 %.

For 617 Ω Coil Network - 0.82 %.

TABLE VIII

VALUES RECOMMENDED BY KEYSTONE

THERMISTOR RL3F1			THERMISTOR RL4F1		
Resistor	Resistance	Deviation For 1000Ω Meter	Resistor	Resistance	Deviation For 1000Ω Meter
R_1	410Ω	0.70%	R_1	234Ω	0.85%
R_2	232Ω		R_2	294Ω	
R_T@ 25°C	246.0Ω		R_T@ 25°C	290.5Ω	
R_C@ 25°C	468Ω		R_C@ 25°C	617Ω	

Theoretically, the expected deviation of the meter over the temperature range resistance is near 1%. Keystone claims to be able to achieve between 0.7% and 0.8% with their thermistors.

In addition to maintaining a constant resistance, the current must also remain constant with respect to changes in temperature. One test sample was tested for accuracy at -28°C, 25°C, and 65°C. It was found that there was a deviation in current over the temperature range. However, this deviation was considered small enough to allow for good temperature compensation. Further tests are contemplated to confirm this point.

ELECTROMAGNETIC INTERFERENCE:

There was a great deal of confusion as to which military standard on EMI the meter should be tested. A study brought to light a large number of standards for EMI testing. However, most of them were cancelled, and they were replaced by Mil-Stds-461, 462, and 463.

Unfortunately, discussions with test engineers at Hopkins Engineering and Cornell-Dubilier indicated that Mil-Stds-461, 462, and 463 were not applicable to a microampmeter. Further discussions resulted in a realistic program for measuring the attenuation and the susceptibility of the meter over frequencies ranging from $14 KH_z$ to $1 GH_z$. Mil-Std-285 will be used as a guide to attenuation measurements, and Mil-Std-461, Sections RS 01, RS 02, and RS 03, will be used as a guide to susceptibility measurements.

Attempts are being made to add to the meter some form of radio frequency shielding. The shielding will be added to the crystal which is made of polycarbonate. The polycarbonate is an insulator, and it is expected to have very poor attenuation characteristics for RF radiation at nearly all frequencies. A conductive material will have to be added to the crystal to obtain adequate attenuation.

Attenuation of electromagnetic waves near an interface between two media is achieved in two ways -- by reflection from the interface of the two media and also by penetration losses in the media. At low frequencies where the magnetic field is the dominating component of the propagating wave, conductors having large permeabilities provide the best attenuation. On the other hand, at high frequencies, the electric field is the dominant component and reflection is the main factor in attenuation. For this reason, at high frequencies the materials with the best conductivity provide the best attenuation.

There are two ways to apply a conductive material to the crystal. One method is to place a fine wire mesh behind the crystal. Attenuation measurements were reported by C. B. Pearlston in the IRE Transactions on Radio Frequency Interference for a number of meshes. The best attenuation was reported for a #10 monel mesh, .016 wire, which gave a constant attenuation of 40 db for frequencies ranging from $14 KH_z$ to $1 GH_z$.

The second method is to apply a coating of conductive material to the crystal. Resistances as small as 2 ohms/square have been coated on glass. Unfortunately, the light transmission of the glass decreases proportionately with decreasing resistivity. Figure 3 gives the relationship between the light transmission properties and the resistance of conductive glass.

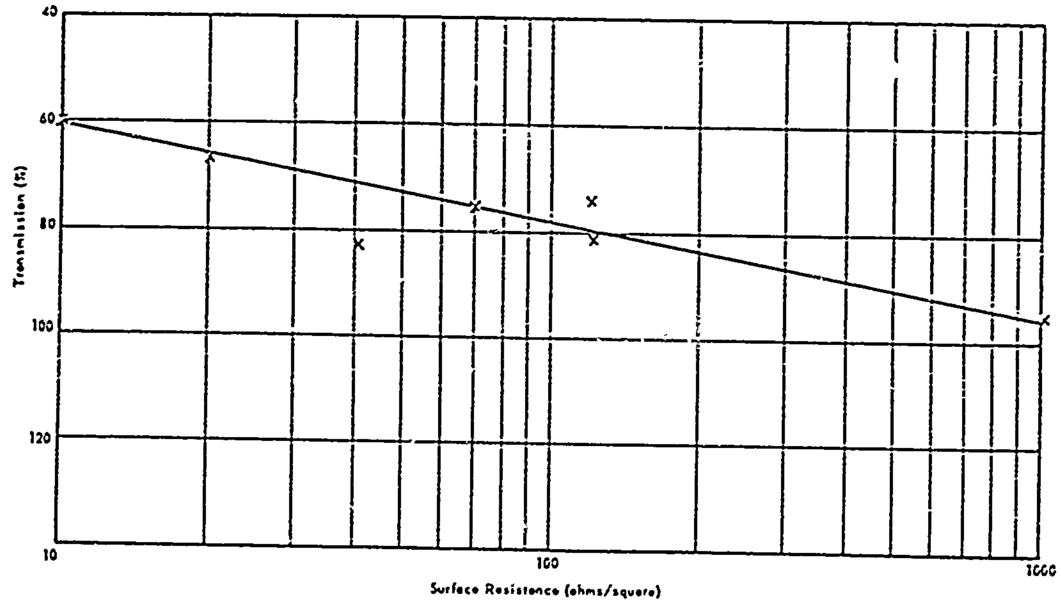


Figure 3

Light transmission vs surface resistance for transparent conductive glass

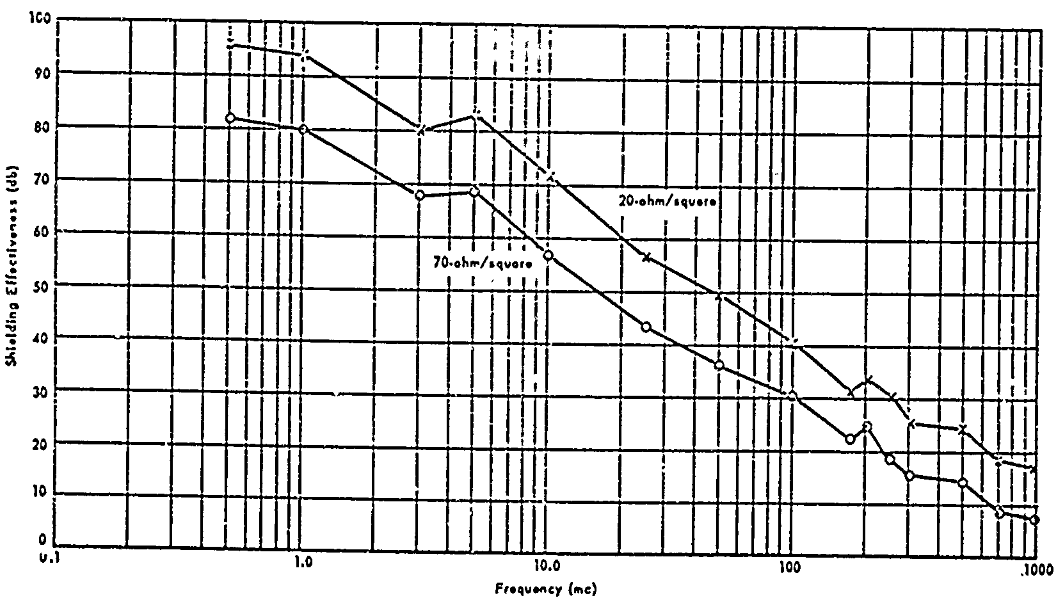


Figure 4

Shielding effectiveness of 70- and 20-ohm/square coated glass

The attenuation properties of conductive glass are not as good as those for wire meshes. Figure 4 gives attenuation characteristics for conductive glasses of twenty ohms/square and seventy ohms per square.

Tests will be made to determine the effectiveness of both modes of attenuation. One meter will be outfitted with a Buckbee-Mears #70 nickel electro-formed mesh having 70 lines per inch. Two other meters will have electrical conductive coatings of 20 ohms/square and 30 ohms/square deposited on the crystals. In the case of the meter with nickel mesh, the crystal will be a sandwich assembly. The mesh will be sandwiched between a .125 thick polycarbonate crystal and a .031 thick acrylic.

The mesh is folded over the edge of the acrylic mask and brought into contact with the case. The case was plated with electroless nickel at the areas of contact with the mesh and with the panel on which the meter is to be mounted.

Only one side of the .125 polycarbonate crystal was coated with a conducting material. This side will be brought into contact with the case of the meter through silver paste applied to the edge of the polycarbonate. Again, the cases were electroless nickel plated where good electrical contacts were required.

EMI tests will be performed to determine both the attenuation of the meter and also its susceptibility to radiation at frequencies ranging from 14 KH_z to 1 GH_z.

HIGH SHOCK AND DIELECTRIC WITHSTANDING VOLTAGE:

High shock tests and measurements of the dielectric withstanding voltage were performed on the first model. These tests completed the program of testing for this unit.

As stated in the previous report, arcing occured between the pointer and the sides of the case at 3,000 VAC. This arcing was eliminated by adding insulation to the sides of the case. The nine meters were built with bumper stops on the dial pan which should increase the dielectric withstanding voltage of the meter.

Two unsuccessful high shock tests were performed with the first model. The meter suffered loose screws and broken taut bands in both cases. It was concluded that the cause was improper spacings between the end springs and the end plates, and between the coil and the core. The unit was rebuilt and the spacings were carefully checked before the third trial. In addition, "Glyptal" was placed on all of the screws in the moving mechanism of the meter. The meter survived the third test and maintained an accuracy slightly less than 2%.

During the first high-shock test the four mounting screws (#6-32, flat head steel) holding the meter to the 1/8 test panel, sheared off during the first three foot top blow, letting the meter fall onto the concrete floor.

The complete series of blows were finally run using hardened steel, socket head screws. As these screws cost 47 cents each and needed a special tool to accomodate the socket head, another test was run using stainless steel, non-magnetic flat lead screws with a normal screwdriver slot. While the screws suffered some deformation due to stretching and damaged threads so that they had to be thrown away after the test, they proved satisfactory for holding the meters.

NINE TEST SAMPLES:

At the conclusion of the testing program for the first unit, construction began on nine samples. Changes were made where difficulties arose with the first model. There were no major changes necessary in the design.

Three taut bands were selected for use in these units -- Carl Haas bands CH 54 and CH 31, and Sigmund Cohn's Pt-10% Ni band. As reported earlier, these bands proved to have favorable characteristics for the meter design.

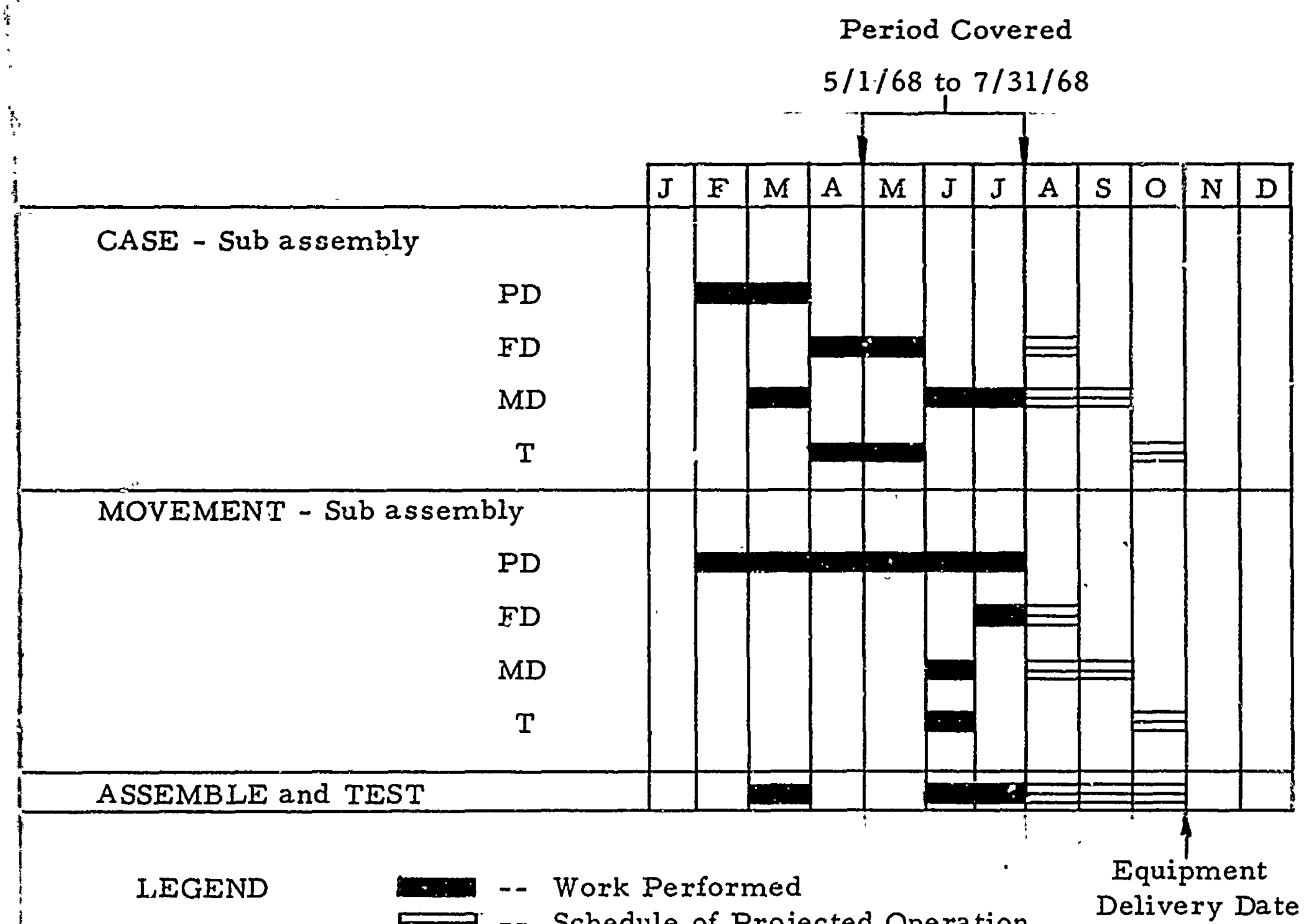
Each band was incorporated in one 40 uA and two 100 uA meters. In each case, one of the 100 uA meters was fitted with a temperature compensation network, and the other will be fitted with EMI shielding.

A complete specification checkout is planned for these nine units.

This completed the work for the quarter.

PHAOSTRON INSTRUMENT & ELECTRONIC COMPANY
PROJECT PERFORMANCE & SCHEDULE
SERIAL NO. XF 02102 TASK 9633

CONTRACT -- N0002467-C-1190 REPORT DATE - 30 August 1968



LEGEND
- ▬ -- Work Performed
- ☰ -- Schedule of Projected Operation
- PD -- Preliminary Design
- FD -- Final Design
- MD -- Model to be Delivered
- T -- Test

Estimated completion in percent of total effort expected to be expended (not chronological).

Case	70%
Movement	75%
Test	50%

CONCLUSION

Of the four taut bands tested, three had suitable properties for the meter design -- moderate torque, small hysteresis, and small after effect. It was also apparent that the band was capable of withstanding the stresses of high shocks. On the other hand, both theoretical treatments and experimental tests indicate that a linearity of 0.5% is practically unattainable with a taut band mechanism.

It is apparent that the stiffness of the end springs will have to be increased in an attempt to reduce the coil sag.

The centering of the coil will have to be improved.

Theoretical studies indicate that temperature compensation networks should be capable of maintaining a voltage drop to within nearly 1% of the value at 25°C. Actual testing will be required to substantiate this conclusion.

Testing will also be required to determine the effectiveness of the proposed EMI shielding.

PART II

PROGRAM FOR THE NEXT QUARTER

Engineering and environmental tests will be completed on nine units to finalize all requirements for the fabrication. Thirty-six units will be assembled and tested.

This quantity will be divided as follows (mod A002) :

a) Type I (40 uA units) 12 samples fabricated and shipped. 9 samples tested. Of the 9 to be tested in accord with Table III of the exhibit, 6 to be subjected to Group I. Divide into samples of 3 each for Groups II and III and subject 3 not previously tested units to Group IV.

b) Type IIa (100 uA non-compensated and without R. F. I. shielding) Same schedule as for Type I.

c) Type IIb (100 uA with temperature compensation and R. F. I. shielding) Same schedule as Type I except that temperature compensation and R. F. attenuation measurements shall also be conducted in Group I.

A final review of all engineering drawings, specification parts lists and other relevent information will be made for transmittal with the units.

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13. ABSTRACT

A successful high shock test on the first model completed its testing program. Upon its completion, nine units were assembled for a complete specification checkout.

Theoretical and experimental studies were conducted to determine the characteristics of four taut bands. Three of these bands were selected on the basis of these studies for the nine units.

Theoretical studies of terminal resistance compensation indicated that a deviation of nearly 1% can be achieved.

Two forms of shielding -- a nickel mesh and conducting glass -- will be tested for shielding effectiveness against electromagnetic interference.

The testing program for the nine units began at the close of the quarter.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ammeters						
Meters						
Torsion Meters						
Measuring Devices (Electrical)						
Suspension Devices						
Suspension Bands						
Alloys						
Radio-frequency Interference						
Thermistors						
Light Transmission						
Hysteresis						