TRANSFER OF KILOWATTHOUR METER STANDARDS

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TRANSFER OF THE KILOWATTHOUR

RP 106 Final Report

April 1975

Prepared for

Electric Power Research Institute*

Prepared by

National Bureau of Standards

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ABSTRACT

An Edison Electric Institute (EEI) - National Bureau of Standards (NBS) research project was conducted in order to determine how accurately the unit of energy (kilowatthour) is maintained in the electric utility laboratories, and to investigate methods of improving the transfer of the unit of energy. This paper discusses the establishment of a testing facility and the evaluation of energy transfer standards. Recommendations are given for the performing of inter-laboratory tests (round-robins) and the use of special containers for shipping standards by commercial airlines.

TABLE OF CONTENTS

TRANSFER OF THE KILOWATTHOUR
(EEI-NBS Research Project RP106)

Introduction:

The legal unit of energy is established and maintained by the National Bureau of Standards in Washington, D.C. and is then disseminated to the electric power companies through the calibration of transport watthour meter standards that must be hand-carried to and from the NBS laboratory. The number of laboratories making direct use of this facility is relatively small but many other laboratories maintain an indirect tie through inter-company "round-robin" checks. Because of the somewhat nebulous link it became expedient that a coordinated study be made to determine the accuracy with which the unit of energy is transferred from NBS and utilized by the utility laboratory; and to investigate ways of improving its transfer, maintenance, and utilization.

There is a close correlation between an electric utility's earnings and meter accuracy. Some companies do sample testing of new and in-service meters. In the sample testing of new meters, a shipment is accepted or rejected on the basis of tests of a few meters. The validity of this method is highly dependent on very accurately maintaining the unit of energy. Also, an electric utility customer expects, and should get, an accurate bill. Without properly maintaining the unit of energy in the standards laboratory, this will not be achieved.

The proposal to make this study was presented by the E.E.I. Meter and Service Committee to the E.E.I. Board of Directors. It was accepted in December, 1970, and was identified as research project RP106.

RP106 was started in October, 1971, as a two-year project in which the following tasks were to be completed:

1. The building of a testing facility to be compatible with NBS equipment.

2. The investigation and assessment of factors affecting standard watthour meter performance.

3. The performing of "round-robin" tests with E.E.I. member laboratories. In this part, the unit of energy would be transferred from NBS to the laboratories by hand-carrying four standard watthour meters with the required interfacing equipment.

4. The construction of containers suitable for shipping standard watthour meters from NBS to electric utility laboratories without significant loss of accuracy.

The RP106 Laboratory (refer to Fig. 1) consisted of four basic sections:

1. The JEMIC Standard.

2. The four portable standard watthour meters (only two shown in diagram), hereafter referred to as the RP106 Standards.

3. The power supply.

4. The control circuit.

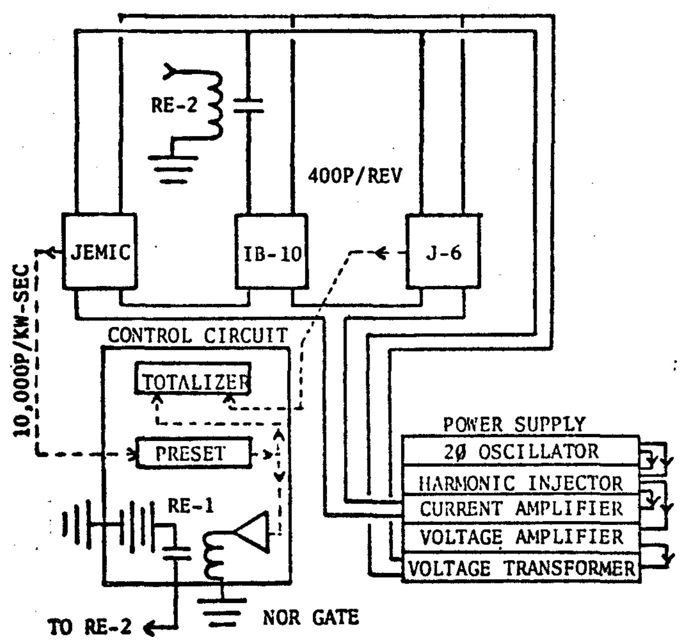


Fig. 1 RP106 Laboratory

1. JEMIC Standard

The reference watthour standard used in RP106 was a meter built by the Japanese Electric Meter Inspection Corporation (JEMIC). The operating principle of this meter is based on the self-balancing system in which the torque produced by an electrodynamic movement is counterbalanced by that of a permanent-magnet moving-coil element in a feedback circuit.

Referring to Fig. 2, the current is carried by the stationary coils and the voltage is applied to the moving coils and series resistance. Power measured by the system produces a torque which causes the shaft to deflect. This creates an unbalance in the capacitance bridge network and produces a voltage change at the junction of R_1 and R_2. This voltage is amplified and converted to a dc voltage by a synchronous rectifier circuit. The dc voltage is then converted by a voltage-to-frequency converter to output pulses that have a frequency of 10 kHz per kilowatt of input power. The output pulses are converted back to a dc voltage with a frequency-to-voltage converter which produces a current through the moving coil in the feedback system. This feedback current creates a torque on the shaft opposite to that produced by the input circuit and brings the system into balance. An output pulse count is a measure of the energy.

The NBS Standard Wattmeter and Standard Time Service were used to determine the ac-dc difference of the JEMIC Standard. At 60 Hz, the ac-dc difference was less than 100 ppm at both 600 watts (unity power factor) and 300 watts (0.5 power factor, current lagging). The overall uncertainties in making these measurements were 44 ppm at unity power factor and 67 ppm at 0.5 power factor. (See Appendix A).

Because the ac-dc difference does not vary with time, only a dc calibration was necessary before using the JEMIC Standard to calibrate the RP106 Standards. The dc power was obtained from a stable electronic supply for the voltage circuit and from batteries for the current circuit. The voltage and current were measured with a standard voltbox and standard resistor, together with a precision potentiometer. The pulse output from the JEMIC Standard was measured with an electronic counter for 10-second intervals. The total uncertainties in the dc calibration were 25 ppm at 600 watts and 39 ppm at 300 watts. (See Appendix A).

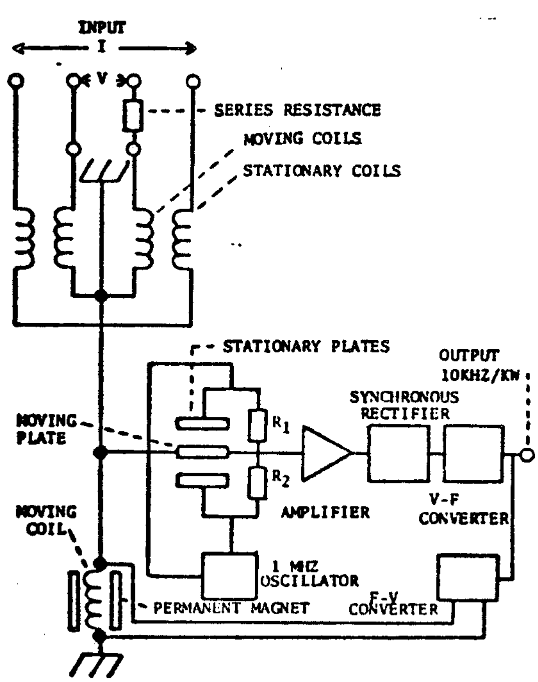


Fig. 2 JEMIC Standard

2. RP106 Standards

Two General Electric Type IB-10 and two Sangamo Type J-6 standard watthour meters were chosen to maintain the unit of energy during the "round-robin" tests.

The IB-10's are standard watthour meters with a three-dial register readout. The dial associated with the pointer directly connected to the rotor is graduated into 100 divisions, the other two pointers have gear reductions of 10 and 100. For a hundred-revolution test, these dials allow a resolution of 100 ppm, or, if one can visually estimate tenths of a division, a resolution of 10 ppm can be obtained.

The J-6's are standard watthour meters with a digital readout. Attached to the rotor is a special disk with sets of one (1), 200, and 400 radial slots arranged in concentric circles. Associated with each set of slots is a lamp and a light-sensitive semiconductor producing one (1), 200, and 400 output pulses, respectively, per revolution of the rotor. The pulses are counted using electronic amplifiers and counters. For a one-hundred-revolution test, counting the pulses from the 400 slot unit would provide a resolution of 25 ppm.

3. Power Supplies

The power to energize the standard meters originated from a two-channel oscillator, where the phase angle between channel 1 (voltage) and channel 2 (current) could be varied ±180°. The output from each channel was fed into a 2-channel third-harmonic injector unit where up to 10% third harmonic could be introduced. The phase of the third harmonic component could be varied up to ±90° with respect to the fundamental. One channel of the injector circuit fed a voltage amplifier; the other fed a current amplifier. With the third-harmonic injector circuit set at zero, the total distortion of each channel was less than 0.05%. The power supply was capable of providing 1600 volts and 50 amperes at frequencies from 10 Hz to 100 kHz.

4. Control Circuit

The control circuit determined the measurement time interval thereby relating it to the energy measured by the JEMIC Standard by counting a preset number of output pulses. The control circuit consisted basically of one preset counter, two totalizers (only one shown in Fig. 1), a gate, an electronic relay RE-1, and a power relay RE-2. After releasing the reset button, the first pulse from the JEMIC Standard arriving at the preset counter changes the gate level from high to low, thus simultaneously enabling the pulse counters connected to the J-6's and energizing the electronic relay RE-1. This, in turn, energizes RE-2 and closes the voltage circuit of the IB-10's. After the JEMIC Standard supplies the preset number of pulses (2,160,000 for a 100-revolution test) the gate level changes from low to high simultaneously inhibiting the counters, stopping the counting of further pulses from the J-6's and disconnecting the potential from the IB-10's.

Using a dual-trace memory oscilloscope, the difference between the opening and closing times of RE-2 was measured and found to be less than 2 milliseconds. For a 100-revolution test, this corresponds to a timing uncertainty for the IB-10's of 6 ppm at 1.0 P.F. and 3 ppm at 0.5 P.F. The contact resistance of RE-2 was 48 milliohms which, by calculation, contributed an error in registration at 0.5 power factor less than 0.02%. The calculation method was checked experimentally using the J-6's with an agreement of 2 ppm. The mathematical treatment and experimental data are given in Appendix B.

Factors Affecting Standard Watthour Meter Performance

A thorough study was made to determine what effect operating conditions would have on the performance of the RP106 Standards.

Before each test, the standard meters were energized at 120 volts and 5 amperes for at least 12 hours. All tests were made at both unity power factor and 0.5 power factor, current lagging. The meters were allowed to run for 100 revolutions in each case. The nominal operating conditions were: 120 volts; 5 amperes; 60 Hertz; 25°C ambient. Throughout this report, the IB-10's will be referred to as RP106-1 (Serial Number 6027424) and RP106-2 (Serial Number 6027617); the J-6's as RP106-3 (Serial Number 18289681) and RP106-4 (Serial Number 18289628). For each of the following tests, tables show the slopes of the curves of each meter near the nominal condition. Also included are tables giving the uncertainties represented by these slopes.

Voltage Test:

The performance of each meter was investigated for voltages from 105 to 135 volts. The results of these tests are shown on Pages 1 through 4 in Appendix C.

The slope of the curves for the meters near 120 volts are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	-0.009%/Volt	-0.006%/Volt
2	-0.009%/Volt	+0.001%/Volt
3	-0.001%/Volt	-0.003%/Volt
4	0.0	0.0

The uncertainties in the performance of each meter under normal operating conditions caused by a voltmeter resolution of ±0.1 volt at 120 volts are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	9 ppm	6 ppm
2	9 ppm	1 ppm
3	1 ppm	3 ppm
4	0 ppm	0 ppm

Instability of the ac voltage was considered negligible.

Current Test:

The performance of each meter was investigated for currents ranging from 4.6 to 5.4 amperes. The results of these tests are shown on Pages 5 through 8 in Appendix C.

The slope of the curves for the meters near 5 amperes are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	+0.03%/ampere	+0.14%/ampere
2	+0.02%/ampere	+0.06%/ampere
3	-0.02%/ampere	+0.06%/ampere
4	-0.02%/ampere	+0.08%/ampere

The uncertainties in the performance of each meter under normal operating conditions caused by an ammeter resolution of ±0.01 ampere at 5 amperes are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	3 ppm	14 ppm
2	2 ppm	6 ppm
3	2 ppm	6 ppm
4	2 ppm	8 ppm

Instability of the ac current was considered negligible.

Frequency Test:

The performance of each meter was investigated at frequencies ranging from 59.5 to 60.5 Hertz. The results of these tests are shown on Pages 9 through 12 in Appendix C.

The slope of the curves for the meters near 5 amperes are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	-0.10%/Hertz	+0.02%/Hertz
2	-0.12%/Hertz	+0.02%/Hertz
3	-0.23%/Hertz	-0.23%/Hertz
4	-0.23%/Hertz	-0.23%/Hertz

The uncertainties in the performance of each meter under normal operating conditions with a frequency stability of ±0.002 Hz at 60 Hz are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	2 ppm	0 ppm
2	2 ppm	0 ppm
3	5 ppm	5 ppm
4	5 ppm	5 ppm

Temperature and Humidity Tests:

The performance of each meter was investigated for temperatures ranging from 20 to 30°C, and relative humidities ranging from 20% to 80%. The results of the temperature test are shown on Pages 13 through 16 in Appendix C. Humidity had no noticeable effect on the performance of the meters and no curves are shown.

The slope of the curves for the meters near 25°C are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	-0.01%/°C	-0.006%/°C
2	-0.01%/°C	+0.006%/°C
3	-0.006%/°C	-0.004%/°C
4	-0.005%/°C	-0.002%/°C

The uncertainties in the performance of each meter under normal operating conditions with a combined temperature instability and thermometer resolution of ±0.1°C at 25°C are:

RP106 Standard	1.0 P.F.	0.5 P.F.
1	10 ppm	6 ppm
2	10 ppm	6 ppm
3	6 ppm	4 ppm
4	5 ppm	2 ppm

Harmonic Tests:

The performance of each meter was investigated for the injection of third harmonic into the sinusoidal current and voltage waves. Because of the magnetic characteristics of the potential circuit, third harmonic components are generated by the sinusoidal voltage which can interact with third harmonic components in the current circuit. Hence, the third harmonic is most likely to affect the accuracy of the meter.

The effect of a harmonic on the accuracy of a watthour meter depends on the phase relationship between the harmonic and the fundamental. Tests were carried out at a total distortion of 1%, 5%, and 10%; one series with a variable phase relationship and a second with a fixed phase relationship.

As a first series of tests, a third harmonic was injected only into the current circuit and its phase relative to the fundamental was varied between +90° and -90°.

In a second series of tests, a third harmonic was injected in both the voltage and current circuits. In each circuit, the harmonic was in phase with the fundamental.

In most meter laboratories, the power is supplied to the standard meters using a phantom loading circuit. It is highly unlikely that harmonic distortion will appear in the voltage source and not in the current source. Therefore, no tests were made to determine what effect injecting a third harmonic only into the voltage circuit would have on the standard meters.

The results of these tests showed no significant differences between the J-6's. The same was found to be true for the IB-10's. Therefore, the graphs on Pages 17 through 19 in Appendix C show the average results for each type.

Stability:

For the J-6's, the average of five 100-revolution tests repeated to better than 50 ppm from day to day, and better than 100 ppm from week to week at both unity and 0.5 power factor, current lagging.

The IB-10 did not perform quite as well as the J-6 but this was to be expected inasmuch as the IB-10 was designed to be a portable type instrument and to be a much more rugged type instrument than the J-6.

Magnetization Test:

The effect of opening the current circuit with 100% rated current at points varying from the peak of the wave to zero crossing was investigated. The change in performance for all four meters was approximately 100 ppm at both unity and 0.5 power factors.

When demagnetizing the meters with currents up to 25 amperes, an unusually large change in registration was noted. However, the meters stabilized subsequently and no similar behavior was observed during any test that followed. The observed large changes are not typical for the types of meters used. No explanation was found for this occurrence.

Stray Field Test:

A conductor carrying 50 amperes was placed within six inches of the four meters. There was no appreciable change in performance.

Steel Table Test:

The meters when placed on a steel table experienced no appreciable change in performance.

Energy Transfer From NBS to RP106

The method of transferring the unit of energy from the NBS Standards to the RP106 Standards is indicated in Fig. 3.

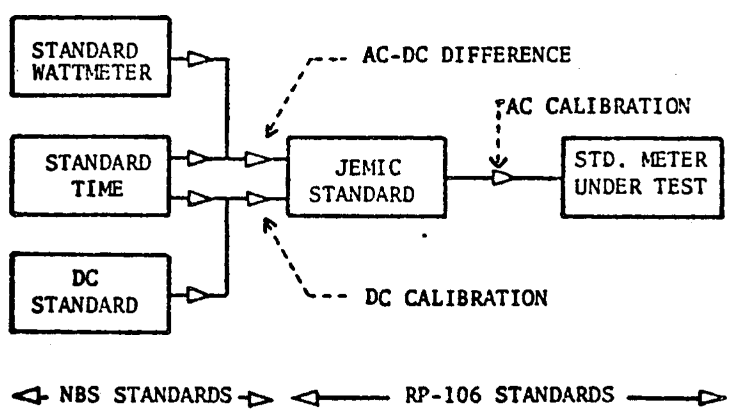


Fig. 3 Energy Transfer From NBS to RP106

The transfer may be divided into three parts: 1) the ac-dc difference of the JEMIC Standard, 2) the dc calibration of the JEMIC Standard, and 3) the ac calibration of the RP106 Standards. The uncertainties associated with these tests for each of the three parts are given in detail in Appendix D. The following table shows the value of the uncertainties based on both the sum and the square root of the sum of the squares.

	RP106-1		RP106-2		RP106-3		RP106-4	
	1.0 P.F.	0.5 P.F.	1.0 P.F.	0.5 P.F.	1.0 P.F.	0.5 P.F.	1.0 P.F.	0.5 P.F.
$\Sigma\varepsilon$ (ppm)	172	253	171	242	157	240	155	235
$\sqrt{\Sigma\varepsilon^2}$ (ppm)	53	79	53	78	52	78	52	77

"Round-Robin" Tests

There were four "round-robins" conducted with E.E.I. member laboratories. Referring to Fig. 4, number 1 was of a preliminary nature that covered only the area in the vicinity of NBS. Number 2 covered the laboratories from the Northeast to the North Central States. Number 3 covered the laboratories from the Southeast to the South Central States. Number 4 covered the Western States. The table below shows a summary of these "round-robins".

	"Round-Robin" 1	2	3	4	Total
Number of Laboratories Visited	6	10	9	5	30
Number of Miles Traveled	2000	4000	6000	8000	20,000
Number of Days	20	40	34	23	117

RP106 "ROUND-ROBINS" WITH E.E.I. MEMBER LABORATORIES

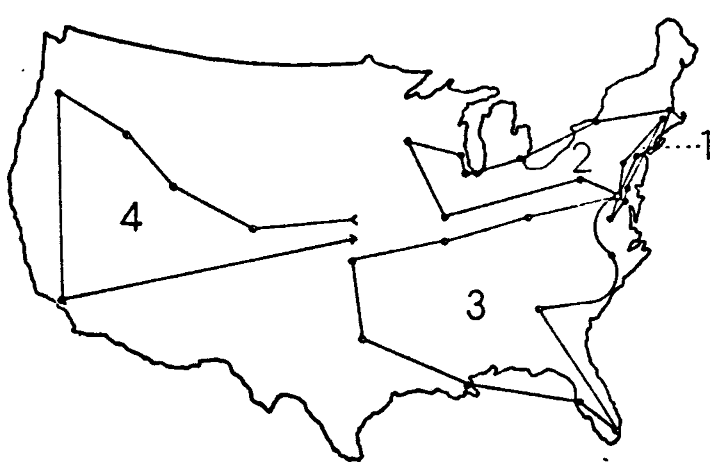


Fig. 4

"Round-Robin" Testing Procedure:

Before departing for a "round-robin" trip, the stability of the J-6's was checked for at least one week. A schedule of the trip was sent to each participating laboratory.

The equipment taken on each trip (see Fig. 5) consisted of the four standard watthour meters, test console, wave analyzer, thermometer, voltmeter (¼%), ammeter (¼%), wattmeter, shunt, leads, and other miscellaneous equipment for self-contained operation of the RP106 Laboratory.

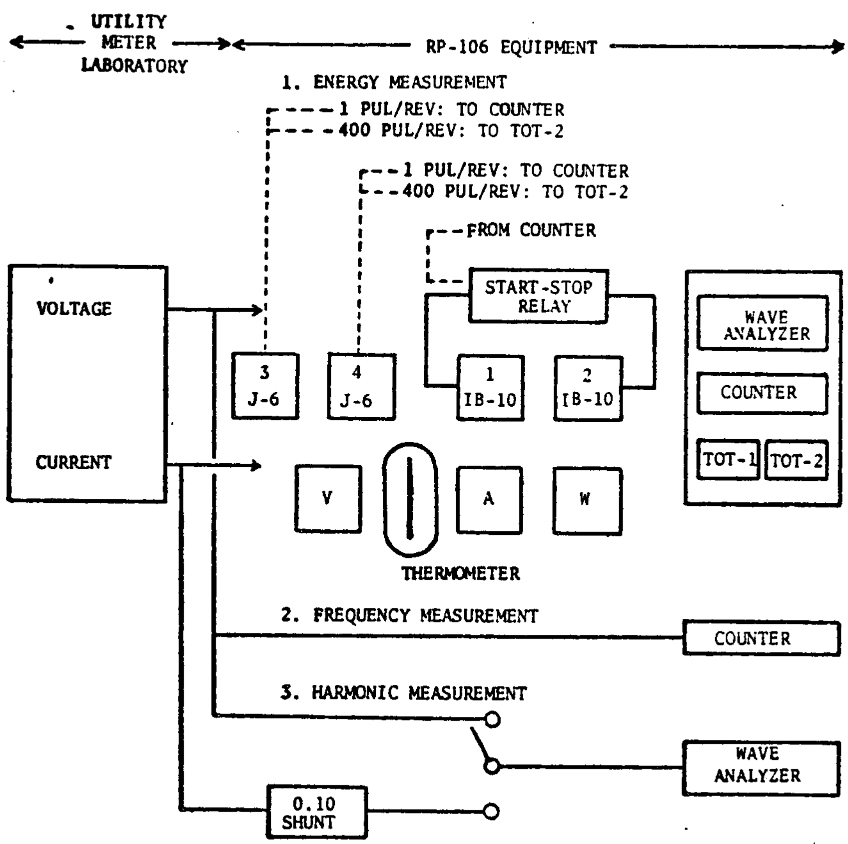


Fig. 5 Equipment used in "Round-Robins"

Two days were required at each utility laboratory. On the first day, no tests were performed. The equipment was set up and left energized overnight to assure that the meters would be at equilibrium with the ambient temperature. The laboratory personnel were then briefed on the testing procedures to be followed on the second day.

On the day of test, the research associate first calibrated the RP106 IB-10's using the RP106 J-6's and associated interface equipment. Tests were made at 120 volts, 5 amperes and at power factors of 1.0 and 0.5 lag. These parameters were measured with the RP106 instruments. Usually, four sets of 100-revolution tests were made at both power factors. Additional runs were made if the repeatability was not within 0.02%. The voltage and current were maintained as close as practicable to their proper values by the research associate. The temperature in the vicinity of the four standard meters was recorded before and after each test.

The RP106 IB-10's were then tested by the utility laboratory personnel, with their equipment and according to their procedures. During these tests, the voltage, current, and power factor were adjusted according to the utility laboratory instruments and monitored with the RP106 instruments. All parameter differences were measured and tabulated. If the utility laboratory had the facilities, the J-6's were then tested.

After the energy measurements were completed, the test console frequency was determined. In all laboratories, the frequency was found to be 60± 0.01 Hertz.

The voltage and current harmonics were measured with a wave analyzer. Since the wave analyzer only detects voltage, a .10-ohm shunt was placed in series with the current circuit. These measurements were made with all of the meters and instruments in the circuit. The results are given in the table below. The harmonics were measured in 27 of the utility laboratories visited.

HARMONIC	H ≤ 0.5%		0.5% < H ≤ 1.0%		1.0% < H ≤ 2.0%		H > 2.0%	
	V	I	V	I	V	I	V	I
2	27	27	0	0	0	0	0	0
3	17	18	5	6	3	2	2	1
4	27	27	0	0	0	0	0	0
5	10	14	6	6	7	4	4	3
6	27	26	0	1	0	0	0	0
7	21	24	6	2	0	1	0	0

After the tests were completed, the utility laboratory was evaluated and recommendations were made for possible improvements in standardizing procedures. Such recommendations are summarized in a later section of this report.

On returning to NBS, the accuracy of the J-6's was again checked. For each of the four trips, the J-6's performance changed less than 100 ppm, indicating the validity of the test method.

The results of the four "round-robins" are shown in Appendix E. In each "round-robin", the laboratories were coded so that each laboratory would know only its own results. These results include the corrections to the RP106 Standards for temperature, voltage, etc.

A summary of the results at unity power factor and at 0.5 power factor is given in Figure 6.

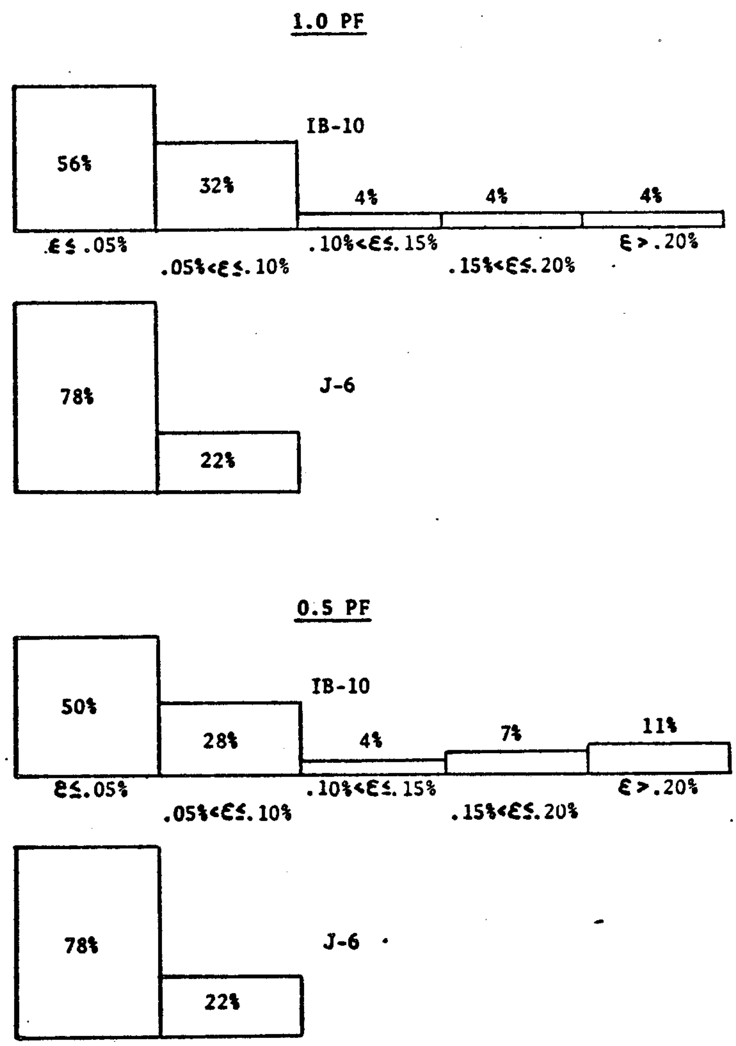


Fig. 6 Summary of "Round-Robin" Results

Shipping Tests

An investigation was made to determine what effect shipping by commercial airlines would have on the accuracy of standard watt-hour meters.

Special shipping containers were obtained for both the IB-10 and J-6 standard meters. The design specification stated that the meter would not be subjected to more than a 10 g shock for a 30-inch drop onto a concrete floor.

The packing material for the IB-10 shipping container was designed and built by the Lelanite Corp., P.O. Box 187, Webster, Mass. 01570. The material was 4-inch-thick rubberized hair with shock mounts in all bearing areas. The container to house the meter and packing material was constructed of 1/8-inch-thick aluminum by the NBS metal shop. Complete shipping containers for IB-10's are now available from the Lelanite Corp.

J-6 shipping containers were designed and built by the Environmental Container Systems, P.O. Box 188, Grants Pass, Oregon 97526. The packing material was 5-inch-thick polyurethane foam in a 3/16-inch-thick fiberglass container. The manufacturer has assigned Part No. CR-335-2866 to this shipping container.

Shipping Procedure

In order to prevent mishandling, the following procedure was followed:

1. The head of the utility laboratory was contacted to make advance arrangements. These included the days of shipping to and from the laboratory, the shipping procedure, and a summary of the tests to be performed.

2. A week before the scheduled test, the airline was contacted and a flight was chosen that had the minimum number of intermediate stops. If possible, transfers from one aircraft to another were avoided.

3. On the day of the flight, about three hours before flight time, the container was taken to the airport by a private messenger service which provided careful handling. All paper work had been completed the day before.

4. Immediately after the scheduled flight time, the air freight office was contacted to confirm that the container was in flight. The utility laboratory was then contacted to give them the air bill number, carrier, flight number, and estimated time of arrival (E.T.A.) so that the shipment could be picked up at the airport immediately after arrival.

5. All shipments were in red containers labeled "this side up" and "delicate instrument". The address of the sender and receiver were clearly marked on the container with the instruction to hold the shipment at the arrival airport.

6. After testing was completed, the same procedure was followed for return of the meter to NBS.

Shipping Test Results

These results of the shipping tests are in the table below. These results show the difference between the before and after shipment registrations.

Three accelerometers (go/no-go type) were attached to the IB-10 cover to indicate shock levels of 10 g, 20 g, and 30 g. The maximum accelerometer indication for each trip is shown.

Shipping Test	Laboratory Location	J-6		IB-10		IB-10
		1.0 P.F.	0.5 P.F.	1.0 P.F.	0.5 P.F.	Shock Level
1	Alhambra, Calif.			+0.007%	+0.006%	20 g
2	Tampa, Fla.	0.000%	-0.001%			
3	Rochester, N.Y.			-0.022%	-0.018%	10 g
4	Milwaukee, Wis.	-0.003%	-0.004%			
5	Dallas, Tex.			+0.036%	+0.044%	20 g

Conclusions

From the preliminary results it looks promising that it will be possible to transfer the unit of energy from NBS to a meter laboratory by shipping a portable standard watthour meter.

The results of the shipping tests indicate that the J-6 can be shipped without significant loss of accuracy. In both of the shipping tests, the J-6 changed less than 0.01% at both 1.0 P.F. and 0.5 P.F. lag.

The shipping tests results on the IB-10 are considered good, but did not show as good repeatability as for the J-6. The largest change for the IB-10 was +0.036% at 1.0 P.F. and +0.044% at 0.5 P.F.

Shipping would eliminate the expense and inconvenience of hand carrying standard meters to NBS, which is the practice now. It would make possible more frequent and more widespread "round-robins" as well as intercomparisons with NBS. The J-6's, IB-10's, and the associated interfacing equipment used in this project can now be used to transfer the unit of energy from NBS to the utility laboratory. Conversely, utility laboratories may ship standards to NBS. The transfer of the unit of energy can be done in four ways:

1. Ship an NBS J-6 and interfacing equipment to utility meter laboratory.
2. Ship an NBS IB-10 to utility meter laboratory.
3. Ship a utility laboratory J-6 to NBS.
4. Ship a utility laboratory IB-10 to NBS.

For methods 3 and 4, the utility laboratory would purchase approved shipping containers for their standards. The utility laboratory may also purchase the J-6 interfacing equipment.

NBS is continuing the shipping tests to gain more experience.

Recommendations

Utility laboratories should establish "round-robin" schedules to take advantage of maintaining the unit of energy with shipping standards. Such a procedure should provide a more accurate unit of energy and also be economically profitable.

Using a "round-robin" procedure, several laboratories would share the expense of one transfer of the watthour from NBS. This could be handled in at least two ways. The procedure would be to have a standard meter shipped to a utility laboratory from NBS according to the recommended shipping procedure. Either this standard could be hand carried to the members of the "round-robin" group or the members could each hand carry a portable standard(s) to one particular laboratory to be calibrated by the NBS Standards. An alternative would be to calibrate a standard meter from one of the members of a "round-robin" group using the NBS Standard. The unit of energy could then be transferred to the remainder of the "round-robin" group with the utility laboratory standard meter.

"Round-robin" tests are also beneficial in determining if a laboratory has systematic errors. Systematic errors are often found with an independent source, as happened during the RP106 "round-robins".

In order to obtain maximum benefit from "round-robin" tests, it is imperative that all sources of error be eliminated where possible. The visits to various utility laboratories throughout the country suggested the following recommendations which may be helpful in improving accuracy and precision of watthour measurements.

Temperature Control

The temperature characteristics of standard meters being compared do not necessarily track, even if they are of the same type. Therefore, it is important to keep the meters at a constant temperature during the measurement. If the laboratory ambient varies by more than 1 or 2°C, it would be preferable to have the standard meters under test enclosed in a temperature controlled air-bath (box).

Voltage Control

The voltage coefficients of standard meters are small but not negligible. It is good practice to use a 1/4% laboratory-type voltmeter (instead of panel instruments) to set the test voltage.

Magnetic Influence

Steel bench tops as well as proximity of steel girders, transformers and other magnetic materials, or single conductors carrying heavy currents should be avoided. These may give rise to systematic errors.

Resistance in Voltage Circuit

Any appreciable resistance in the voltage circuit will give rise to errors, particularly at 0.5 power factor. (See Appendix B).

Abrupt Current Switching

It is recommended that the current through the standard meters be increased and decreased gradually (e.g. using a variable transformer) to avoid possible magnetization of the core.

Incorrect Power Factor

In a few cases, test boards were found to be incorrectly wired with the current leading instead of lagging in the half-power-factor setting. This will produce substantial errors and some provision for testing the phase angle should be available.

Time Interval

To eliminate the effects of starting and stopping errors and to obtain the required resolution, the measurement time should be 100 seconds or more.

APPENDICES

APPENDIX A

UNCERTAINTIES IN AC-DC DIFFERENCE OF THE J.E.M.I.C. STANDARD

Uncertainties in ac-dc difference of standard wattmeter:	1.0 P.F. = 0	0.5 P.F. = 40 ppm
Resolution of standard wattmeter:	1.0 P.F. = 35 ppm	0.5 P.F. = 35 ppm
Resolution of JEMIC Standard:	1.0 P.F. = 16 ppm	0.5 P.F. = 32 ppm
Stability of ac power:	1.0 P.F. = 20 ppm	0.5 P.F. = 20 ppm
Stability of dc power:	1.0 P.F. = 10 ppm	0.5 P.F. = 15 ppm

$\Sigma\varepsilon$ 1.0 P.F. = 81 ppm $\sqrt{\Sigma\varepsilon^2}$ 1.0 P.F. = 44 ppm
0.5 P.F. = 142 ppm 0.5 P.F. = 67 ppm

UNCERTAINTIES IN DC CALIBRATION OF THE J.E.M.I.C. STANDARD

Resolution of the JEMIC Standard:	1.0 P.F. = 16 ppm	0.5 P.F. = 32 ppm
Stability of the dc voltage:	1.0 P.F. = 5 ppm	0.5 P.F. = 5 ppm
Stability of the dc current:	1.0 P.F. = 5 ppm	0.5 P.F. = 10 ppm
Uncertainties of the potentiometer	1.0 P.F. = 10 ppm	0.5 P.F. = 10 ppm
Uncertainties of the standard cells:	1.0 P.F. = 10 ppm	0.5 P.F. = 10 ppm
Uncertainties of the standard voltbox:	1.0 P.F. = 6 ppm	0.5 P.F. = 6 ppm
Uncertainties of the standard shunt:	1.0 P.F. = 10 ppm	0.5 P.F. = 10 ppm

$\Sigma\varepsilon$ 1.0 P.F. = 62 ppm $\sqrt{\Sigma\varepsilon^2}$ 1.0 P.F. = 25 ppm
0.5 P.F. = 83 ppm 0.5 P.F. = 39 ppm

APPENDIX B

EFFECT OF RESISTANCE IN POTENTIAL CIRCUIT

The contact resistance of RE-2 was measured to be 48 milliohms. The following equation was used to determine the error introduced by this resistance:

$\varepsilon = (R/X) \tan\theta \times 100$, where ε = error in percent
R = contact resistance in ohms
X = potential coil reactance in ohms
$\tan\theta$ = power factor

The reactance of the potential coil of an IB-10 is 900 ohms. For a relay contact resistance of 48 milliohms, the error in registration of 0.5 P.F. lag for each of the two IB-10's was:

$$\varepsilon = [0.048\ \Omega/(900\ \Omega//900\ \Omega)] \times 1.732 \times 100$$

$$= (0.048/450) \times 1.732 \times 100$$

$$= 0.0185\% \text{ or } 185 \text{ ppm}$$

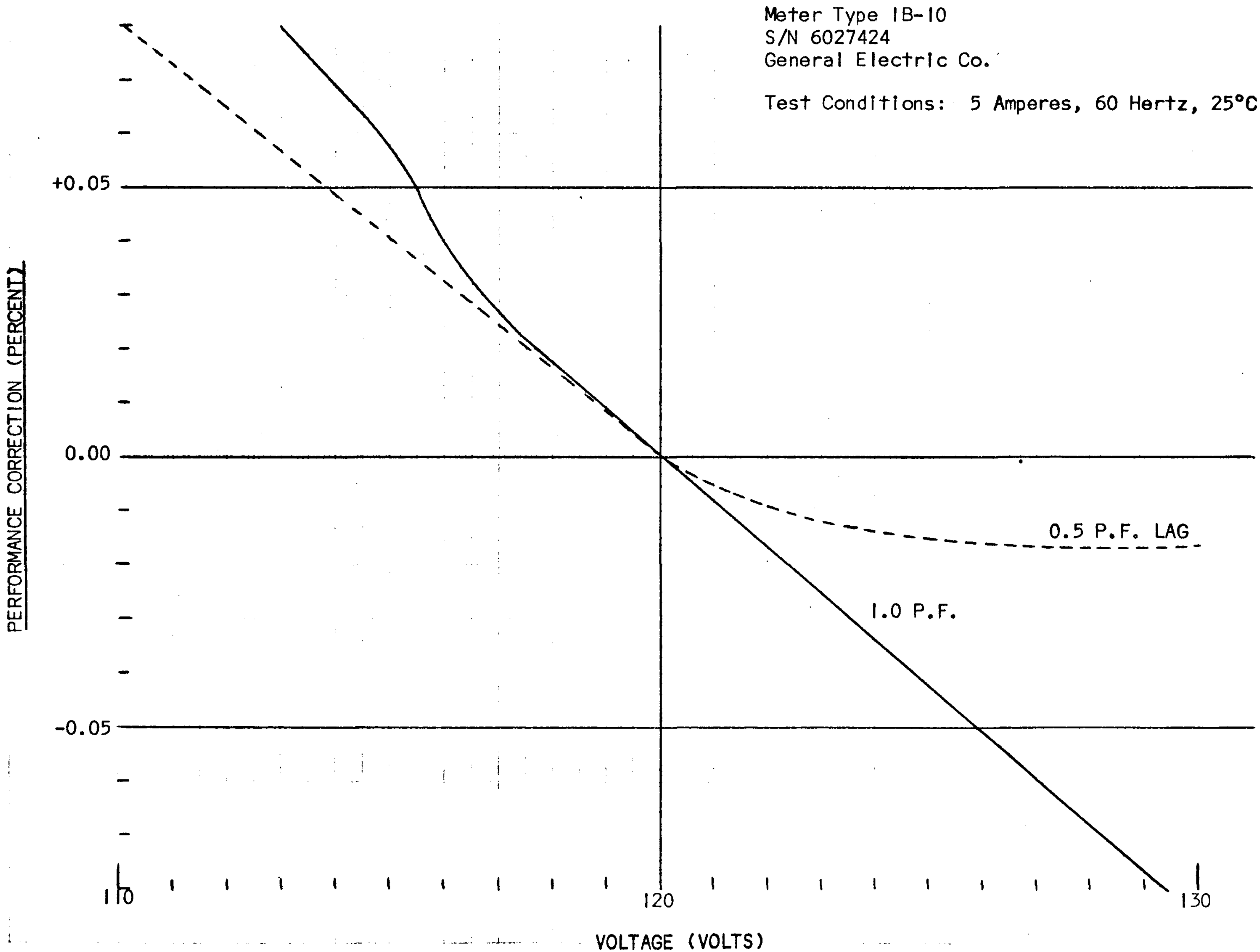
To check this equation experimentally, two J-6's were used in the place of the IB-10's. First, the relay contacts were jumped with a copper bar and the J-6's were calibrated. Second, the copper bar was removed putting the 48 milliohms in the potential circuit. The J-6's were again calibrated. The average change in percent registration between condition 1 and condition 2 was:

$$\varepsilon = R_1 - R_2 = 99.3425\% - 99.3254\%$$

$$= 0.0171 \text{ or } 171 \text{ ppm}$$

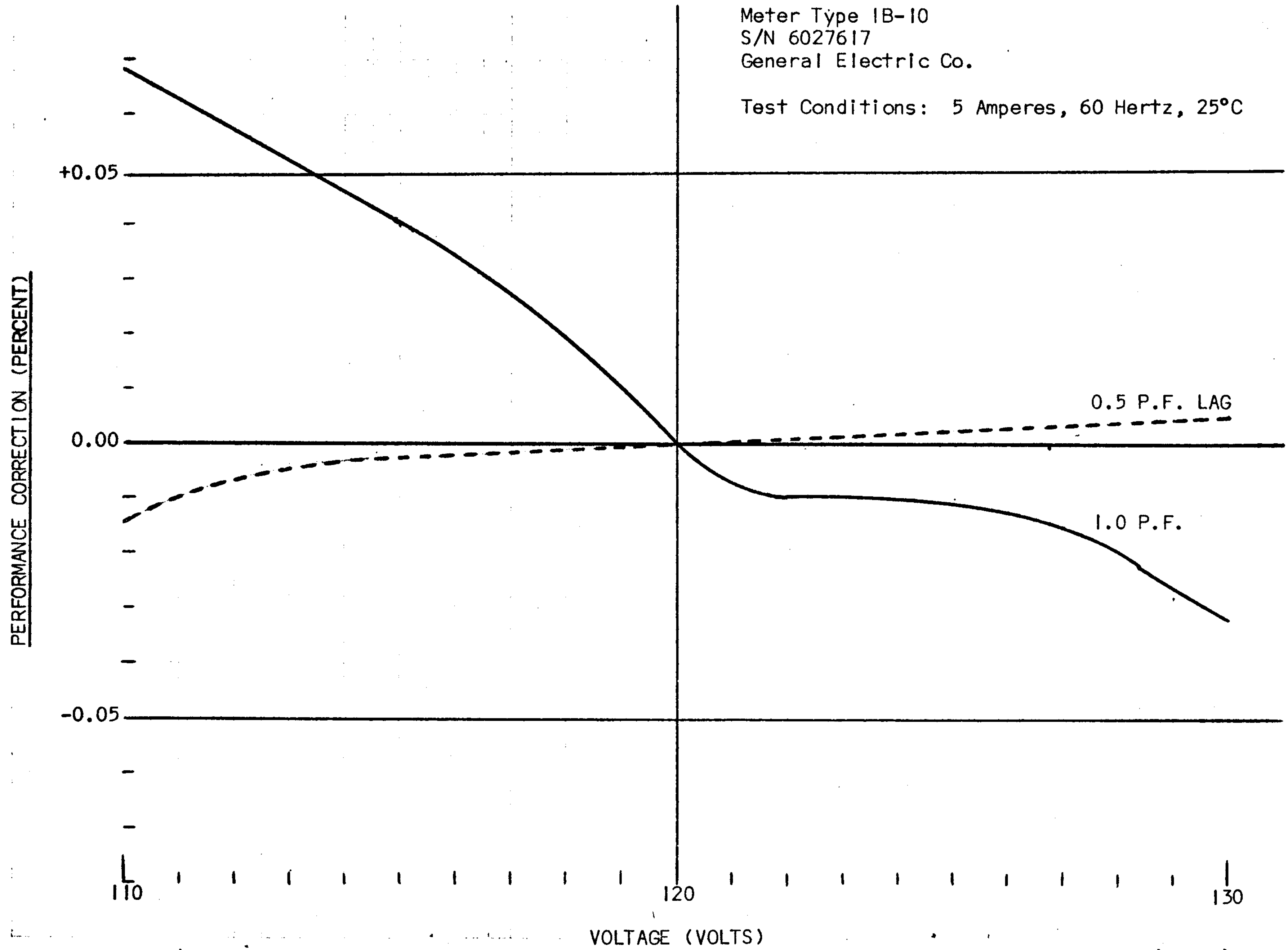
The reactance of the potential coils of a J-6 is 960 ohms. Using the resistance error equation, and the contact resistance of 48 milliohms, ε = 173 ppm for each J-6. The difference between the experimental and calculated values is 2 ppm (essentially zero).

VOLTAGE CHARACTERISTICS FOR RP106-1

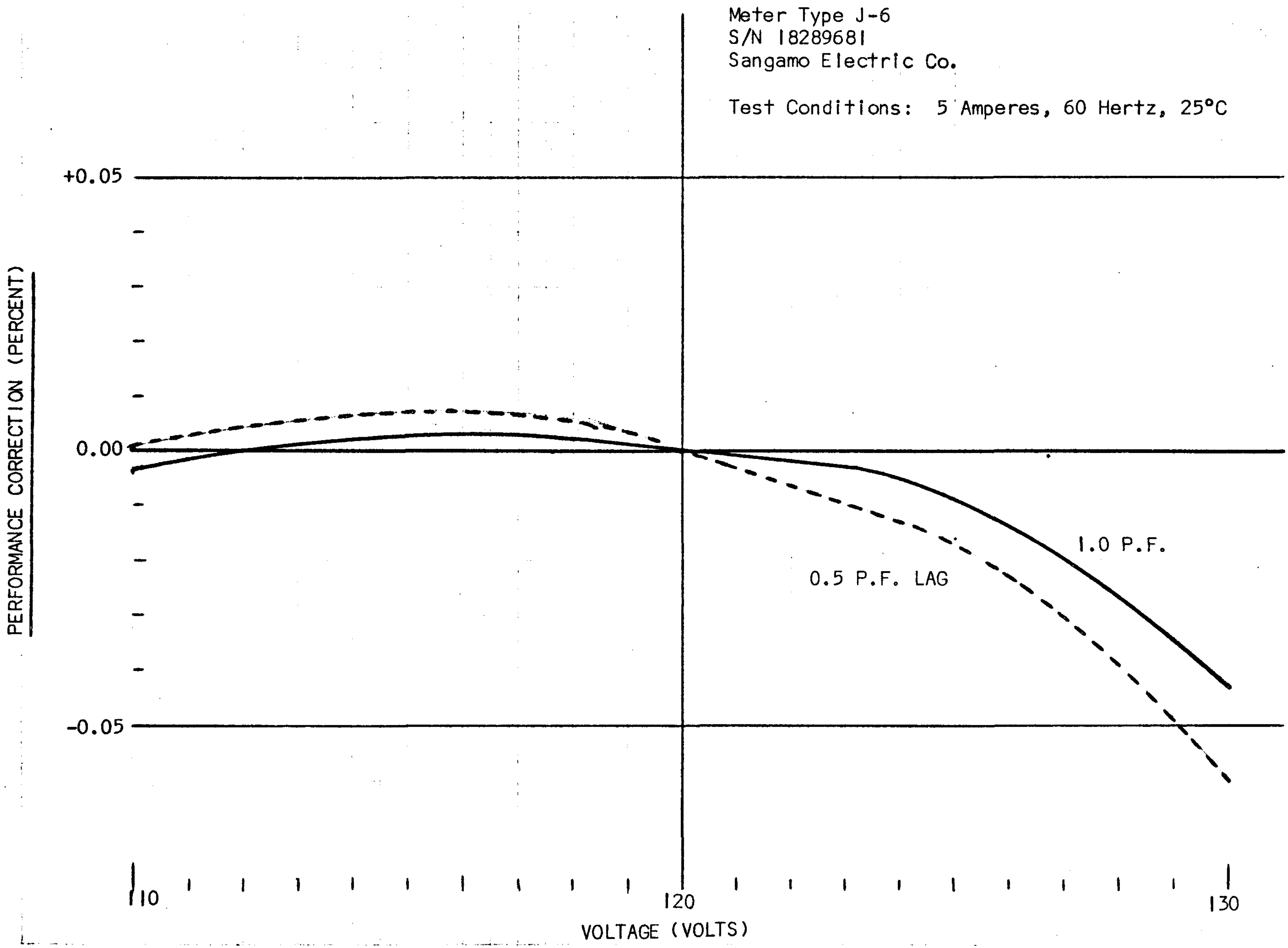


APPENDIX C

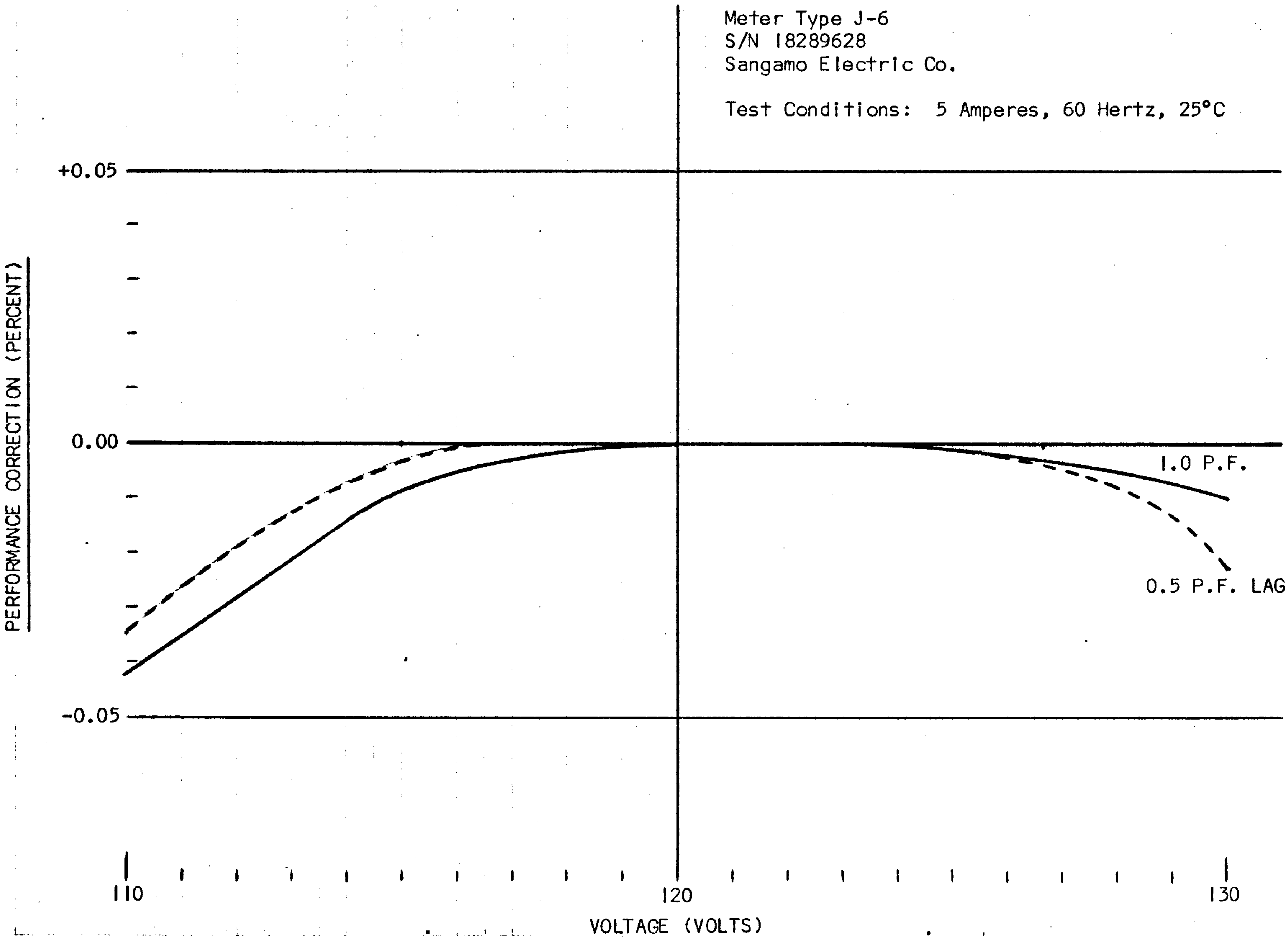
VOLTAGE CHARACTERISTICS FOR RP106-2



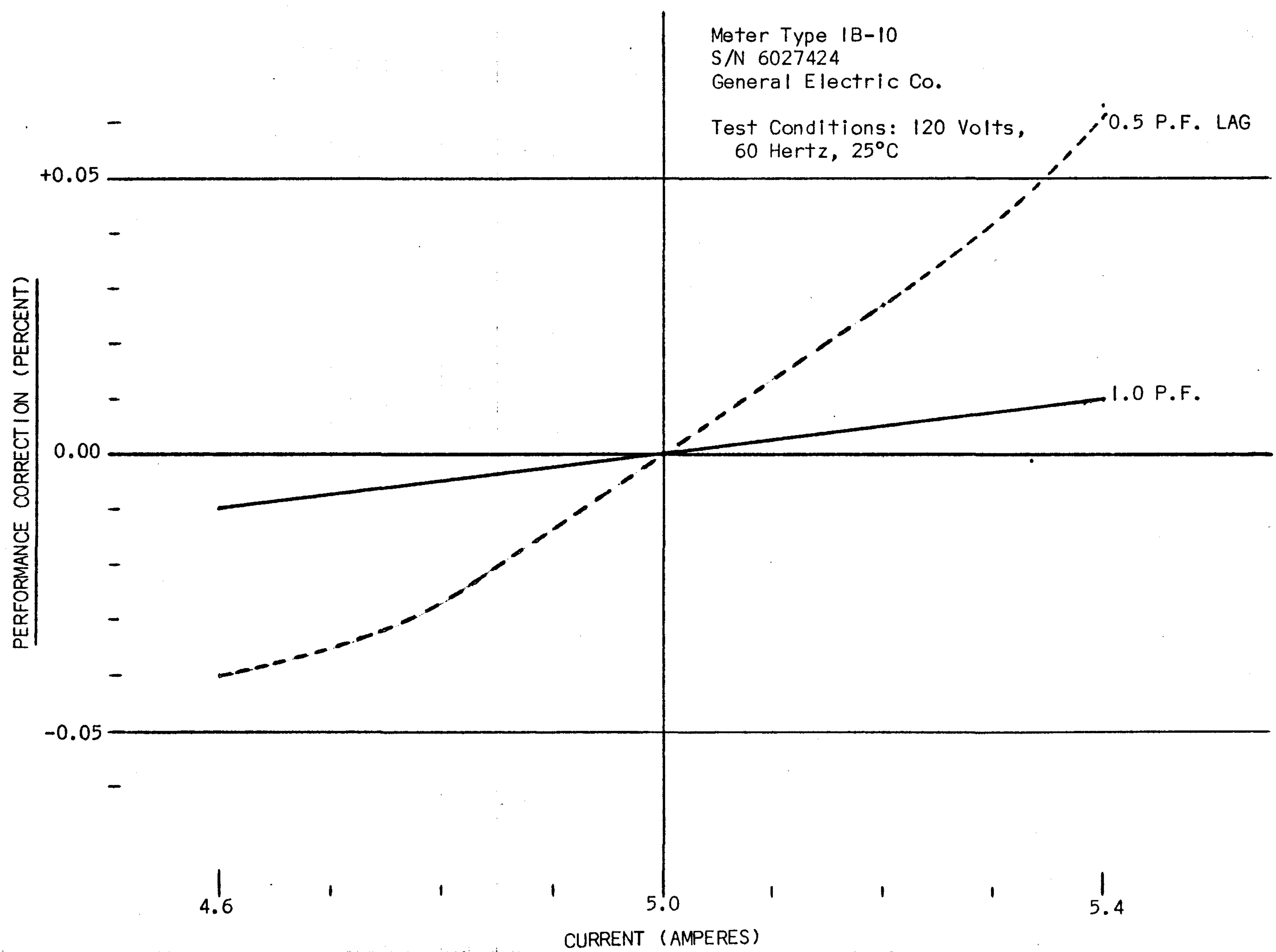
VOLTAGE CHARACTERISTICS FOR RP106-3



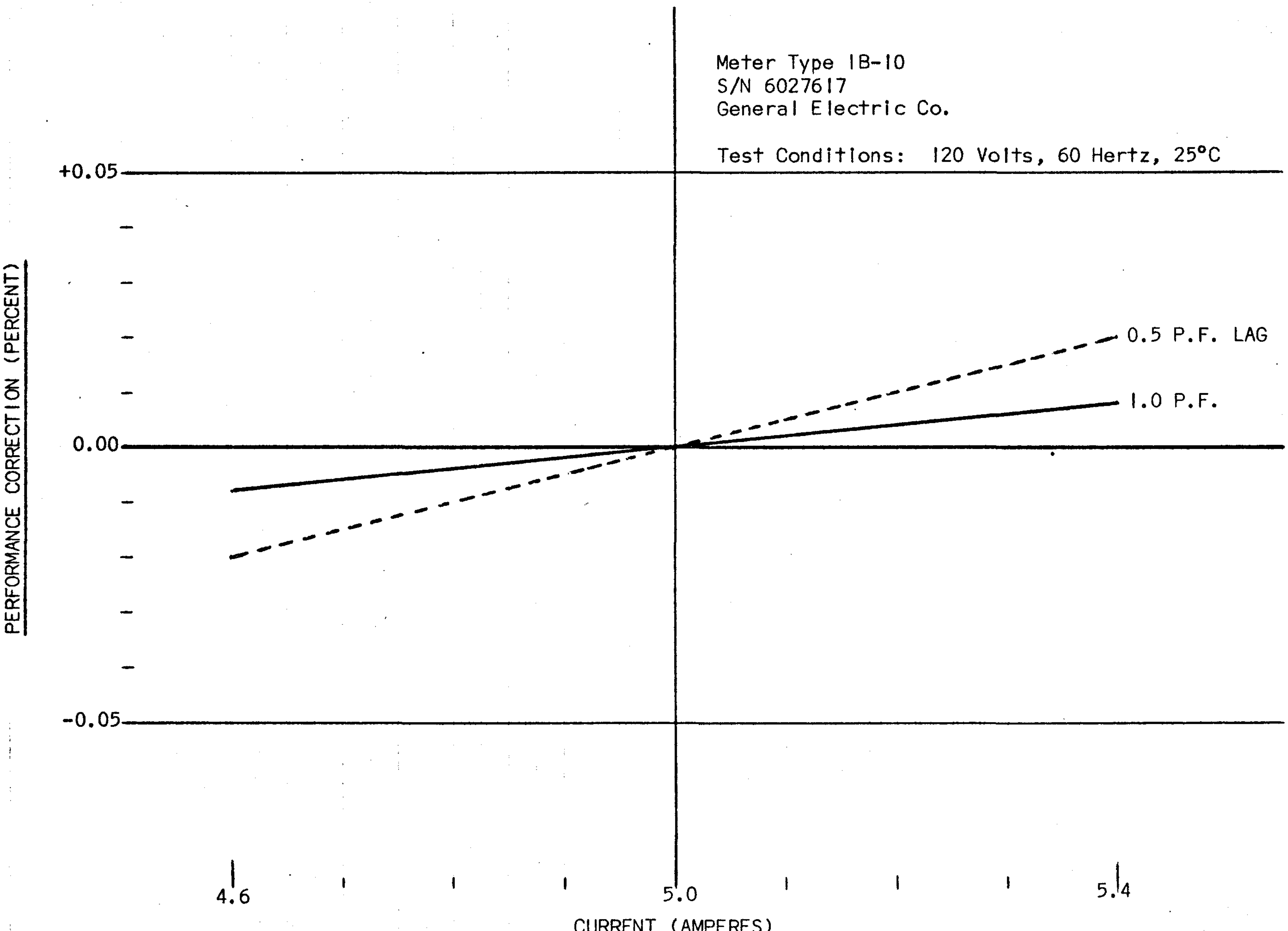
VOLTAGE CHARACTERISTICS FOR RP106-4

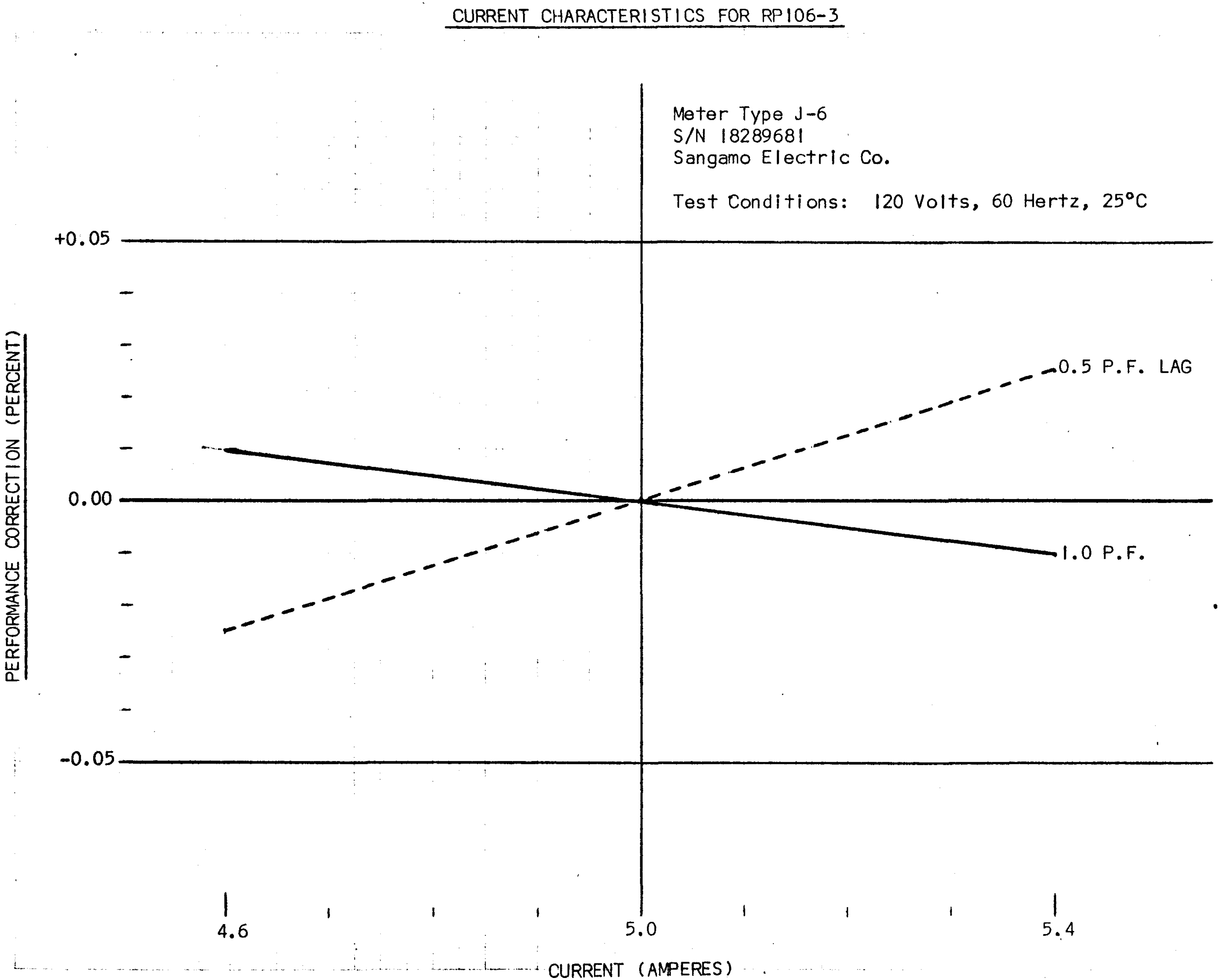


CURRENT CHARACTERISTICS FOR RP106-1

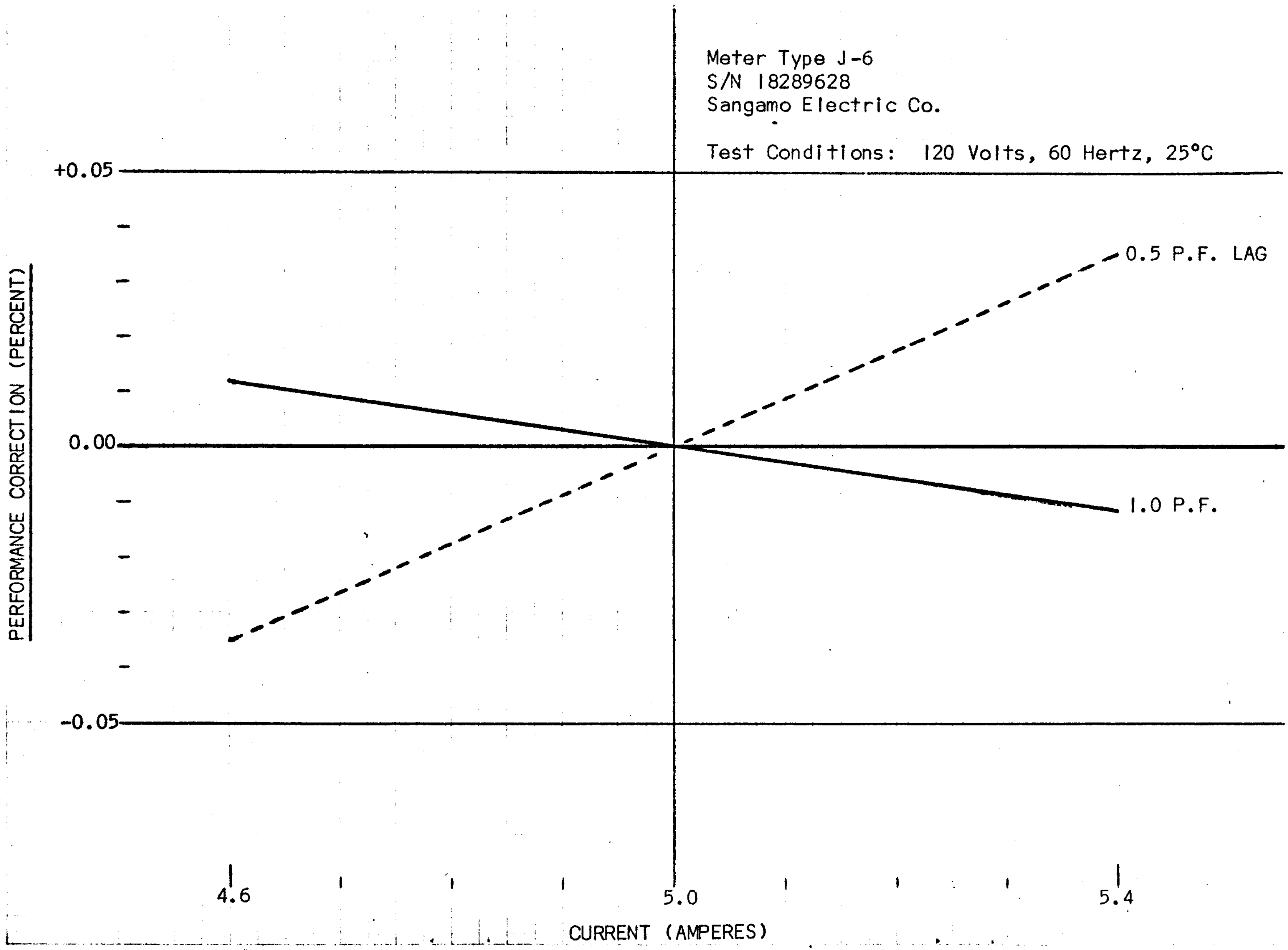


CURRENT CHARACTERISTICS FOR RP106-2

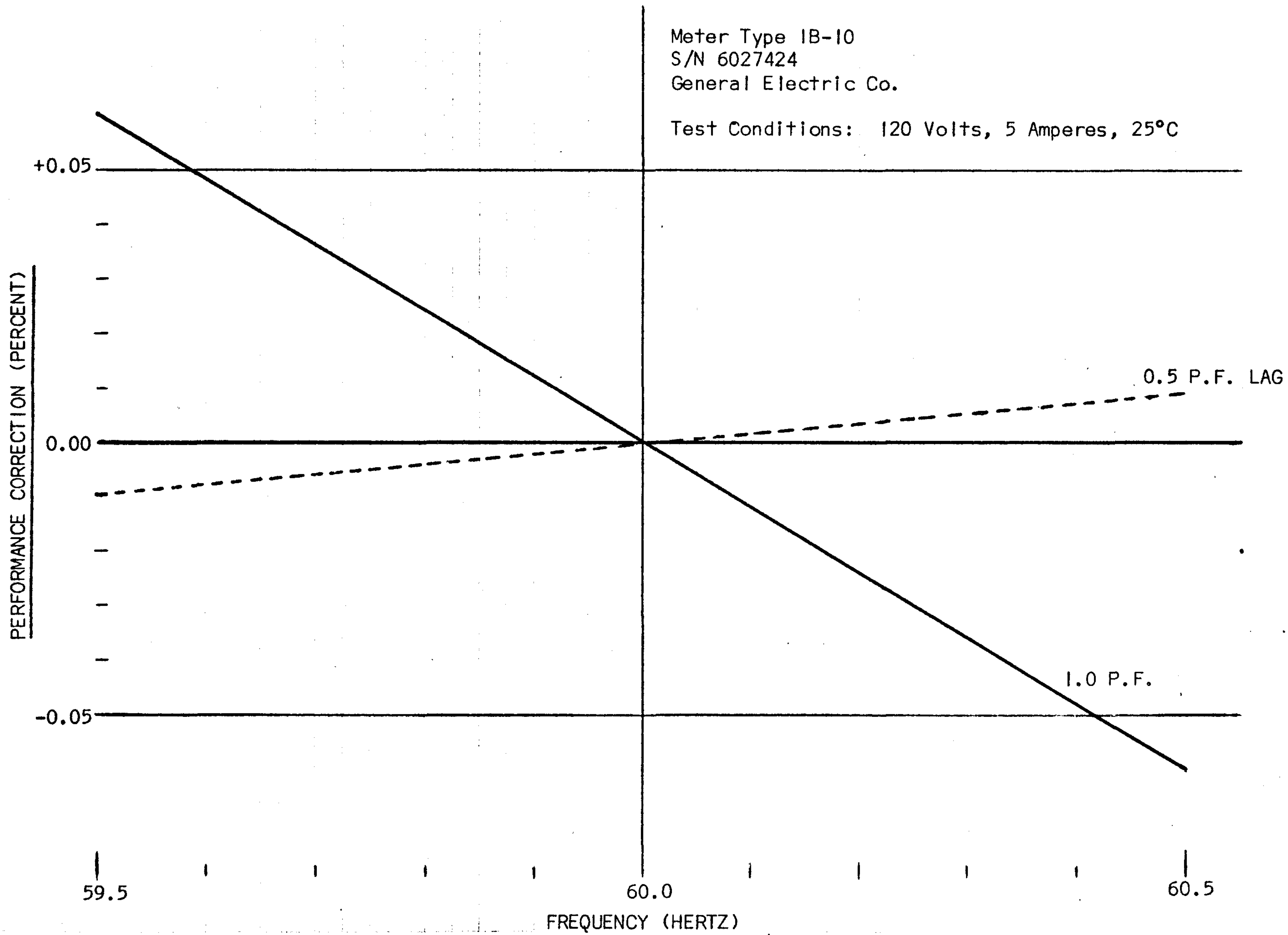



CURRENT CHARACTERISTICS FOR RP106-3
Meter Type J-6
S/N 18289681
Sangamo Electric Co.
Test Conditions: 120 Volts, 60 Hertz, 25°C
+0.05
0.00
-0.05
PERFORMANCE CORRECTION (PERCENT)
0.5 P.F. LAG
1.0 P.F.
4.6
5.0
5.4
CURRENT (AMPERES)

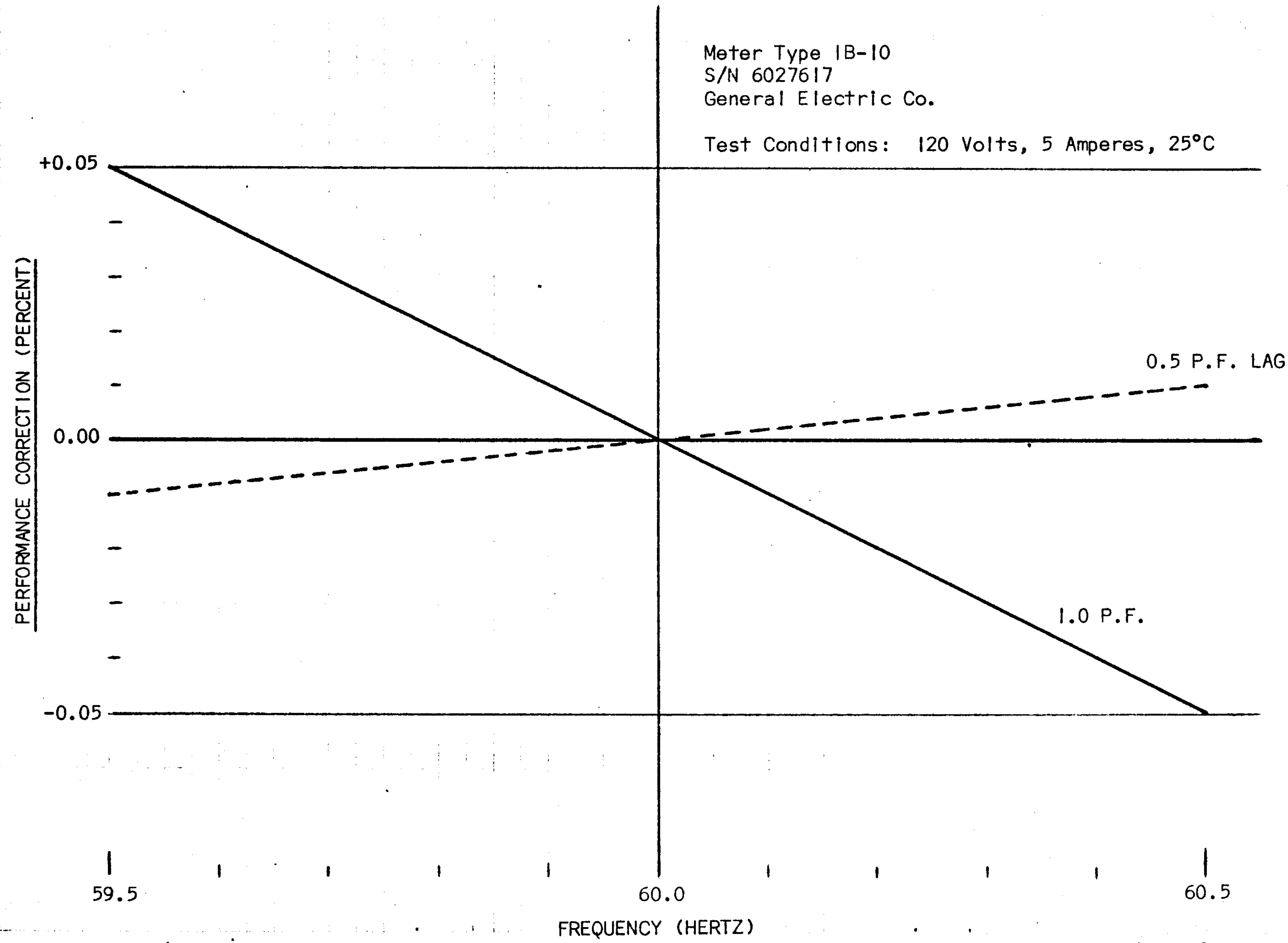
CURRENT CHARACTERISTICS FOR RP106-4



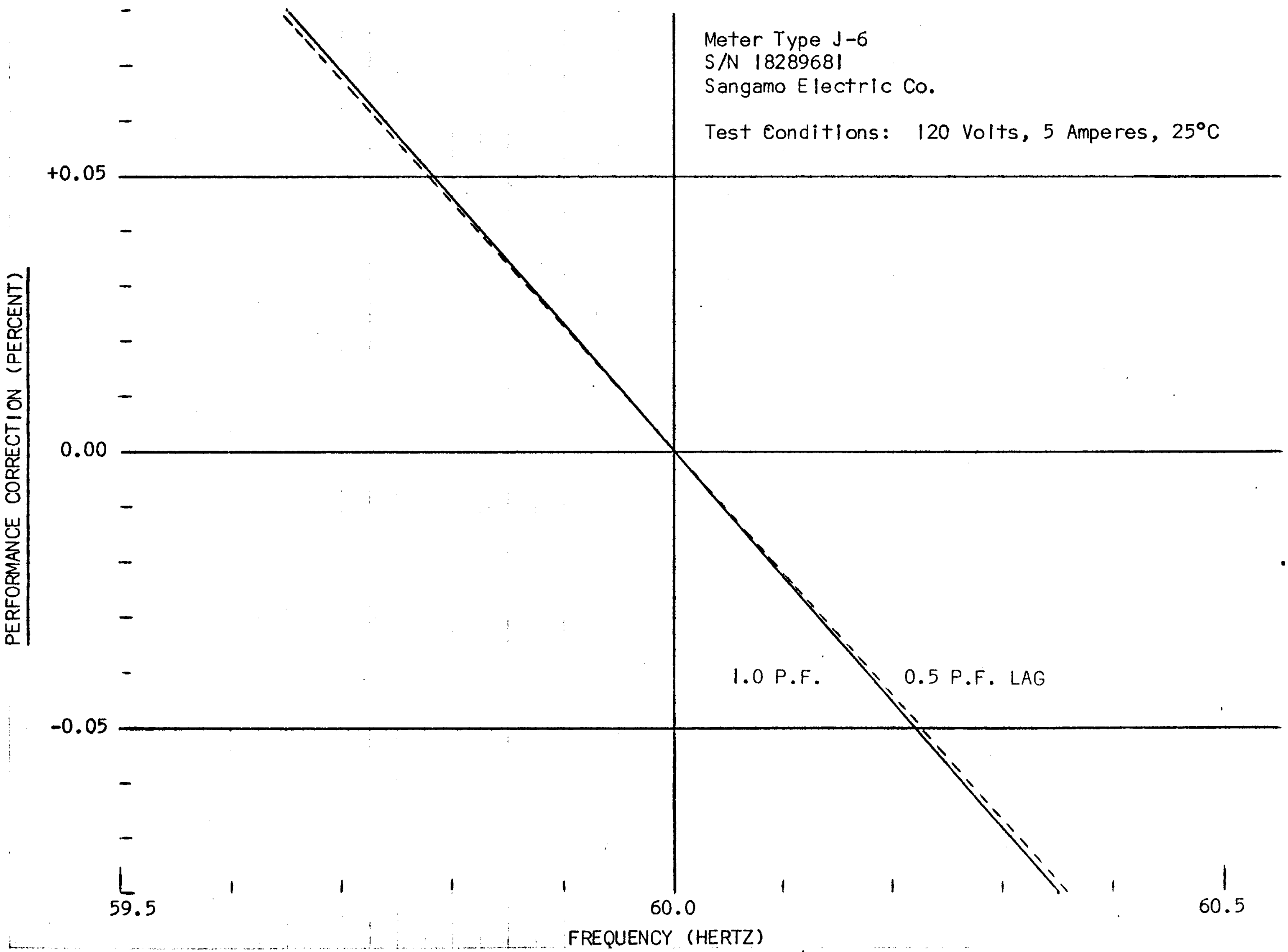
FREQUENCY CHARACTERISTICS FOR RP106-1

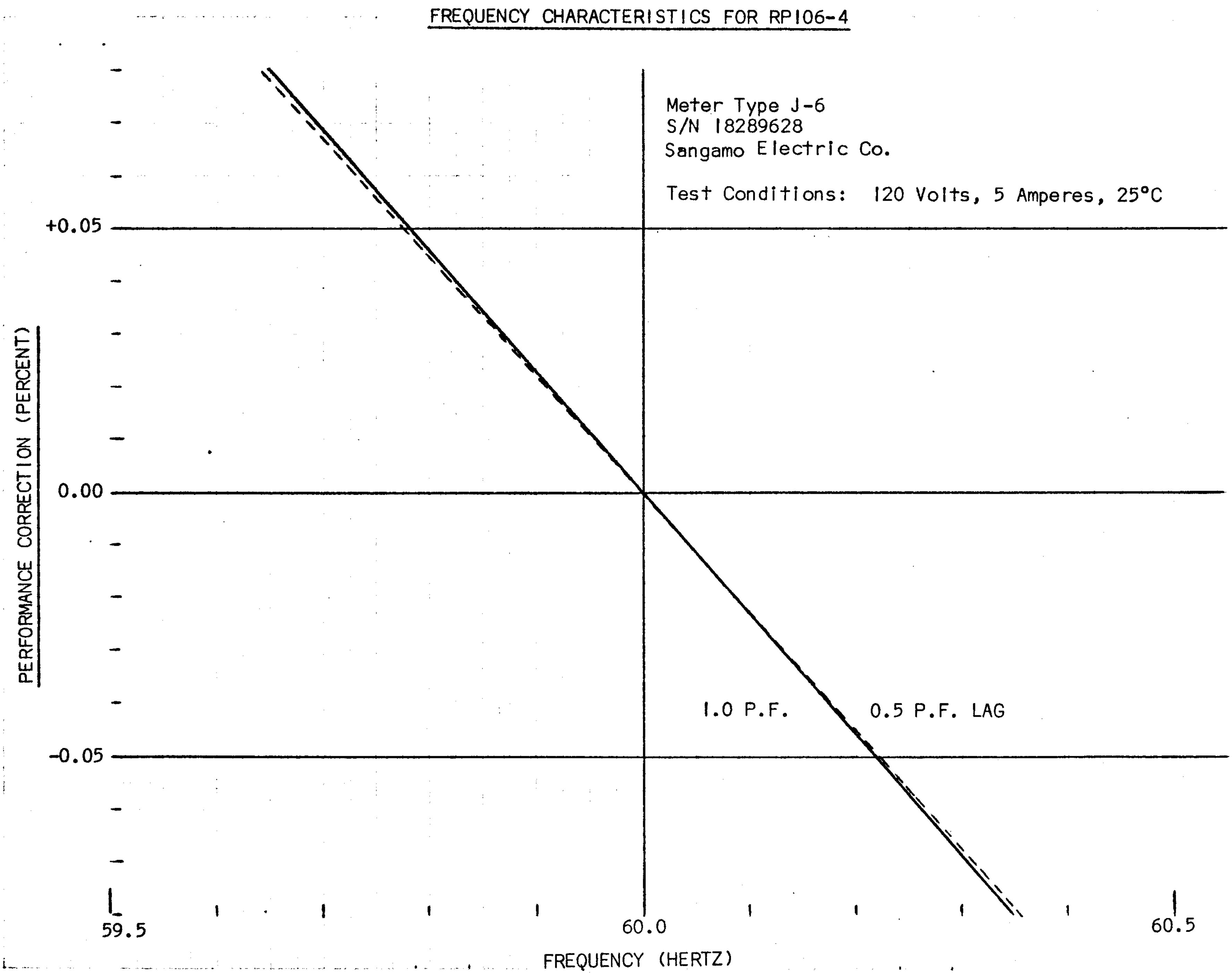


FREQUENCY CHARACTERISTICS FOR RP106-2

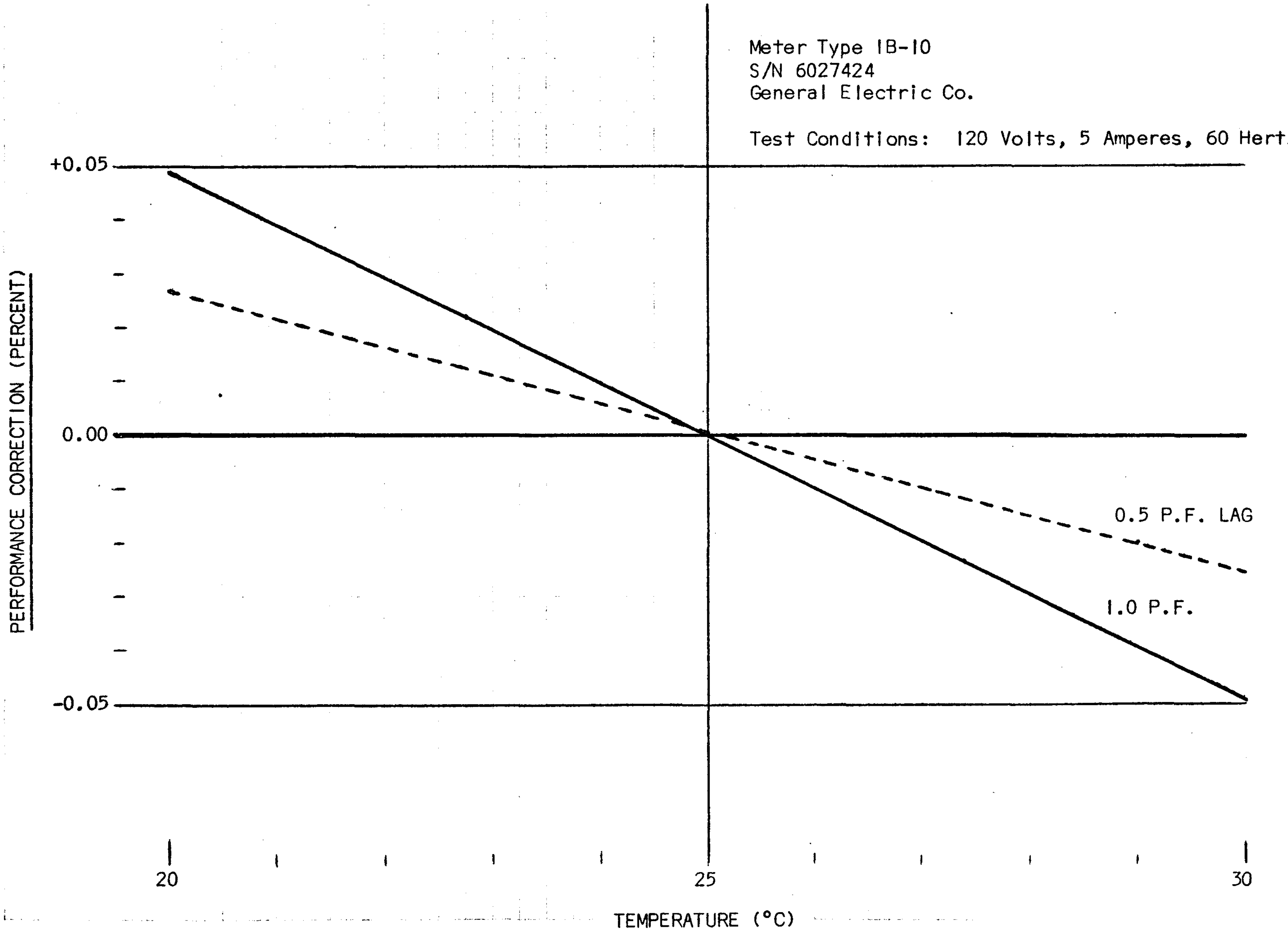


FREQUENCY CHARACTERISTICS FOR RP106-3

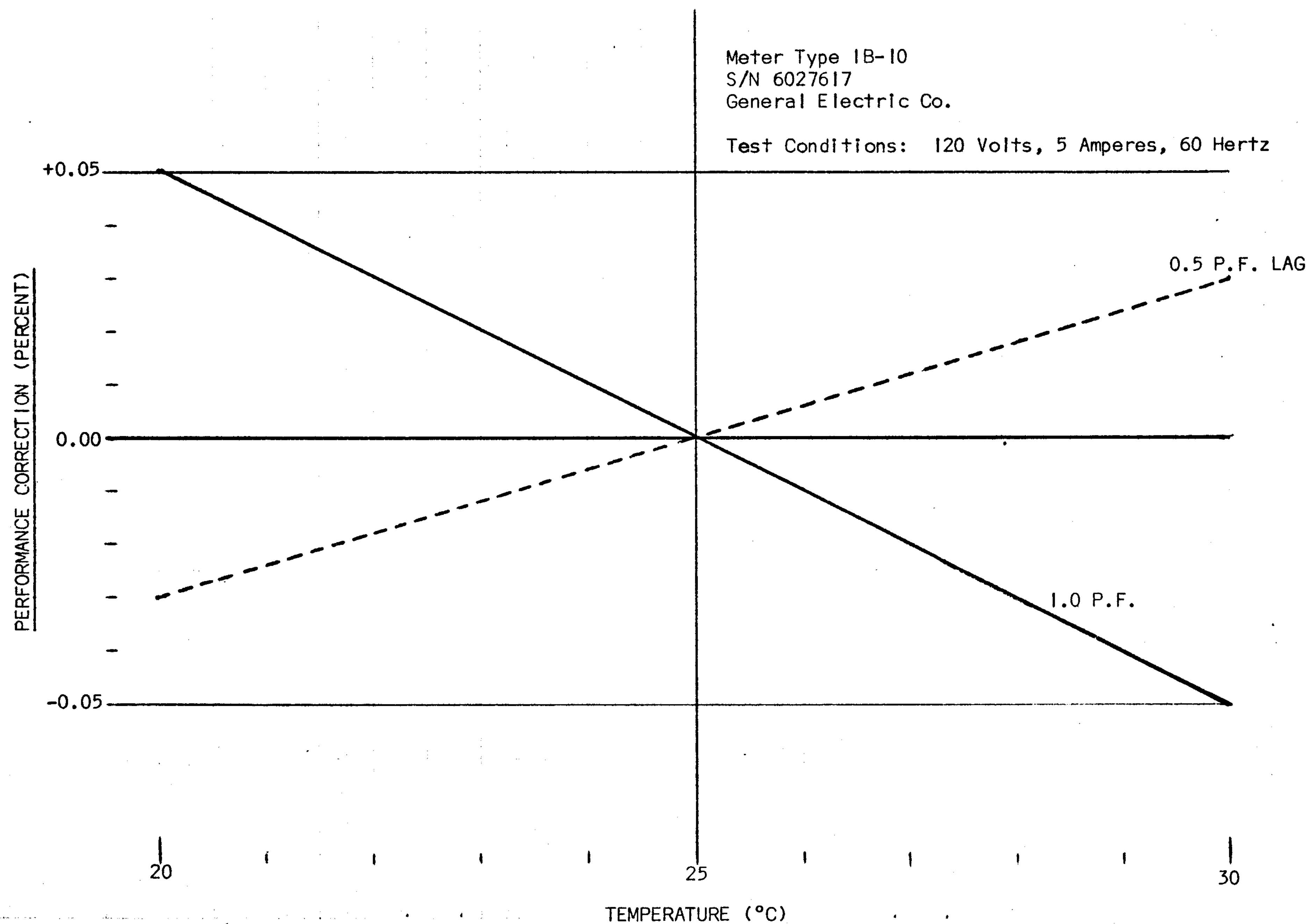



FREQUENCY CHARACTERISTICS FOR RP106-4
Meter Type J-6
S/N 18289628
Sangamo Electric Co.
Test Conditions: 120 Volts, 5 Amperes, 25°C
+0.05
0.00
-0.05
PERFORMANCE CORRECTION (PERCENT)
1.0 P.F.
0.5 P.F. LAG
59.5
60.0
60.5
FREQUENCY (HERTZ)

TEMPERATURE CHARACTERISTICS FOR RP106-1

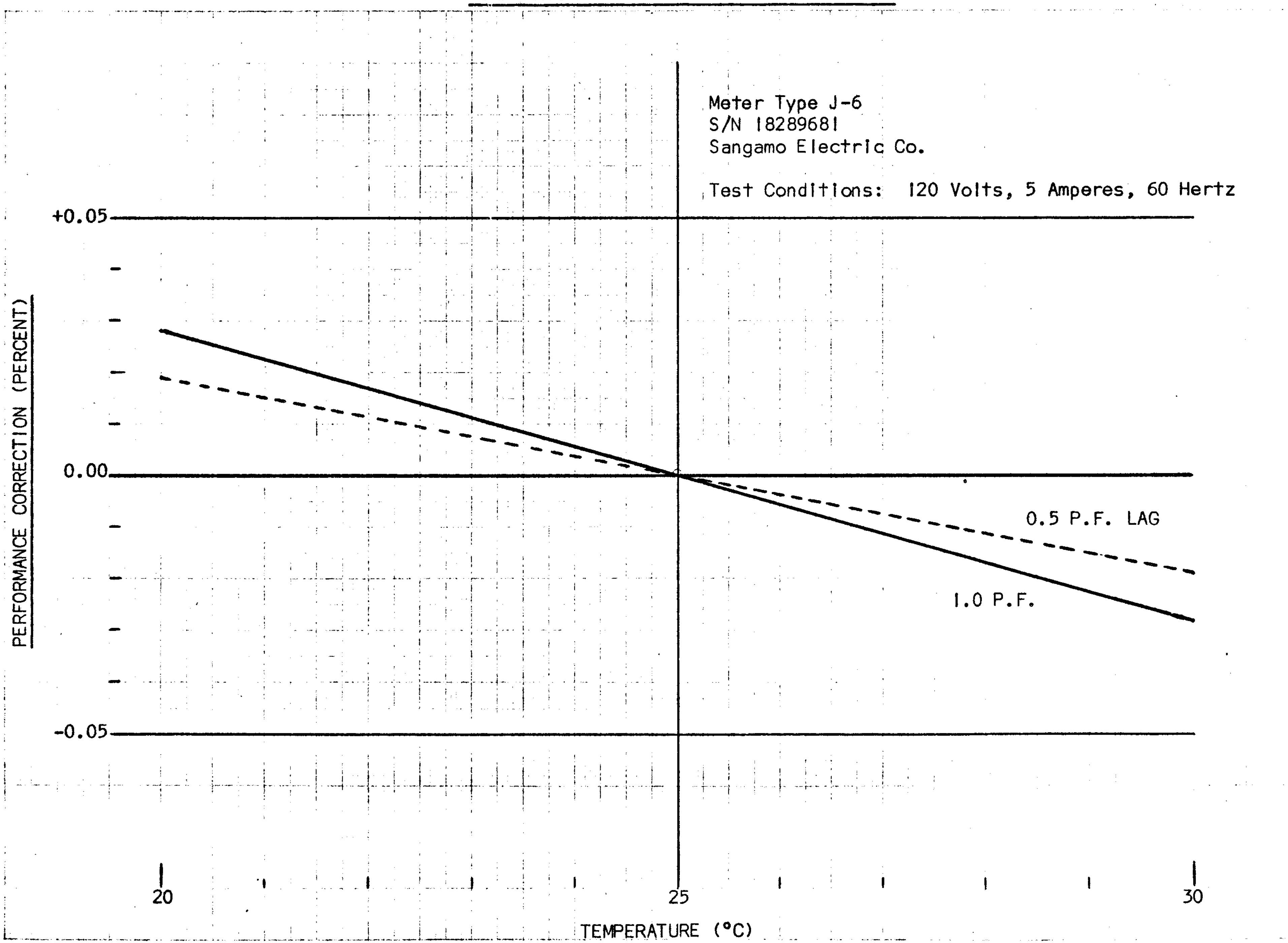


TEMPERATURE CHARACTERISTICS FOR RP106-2

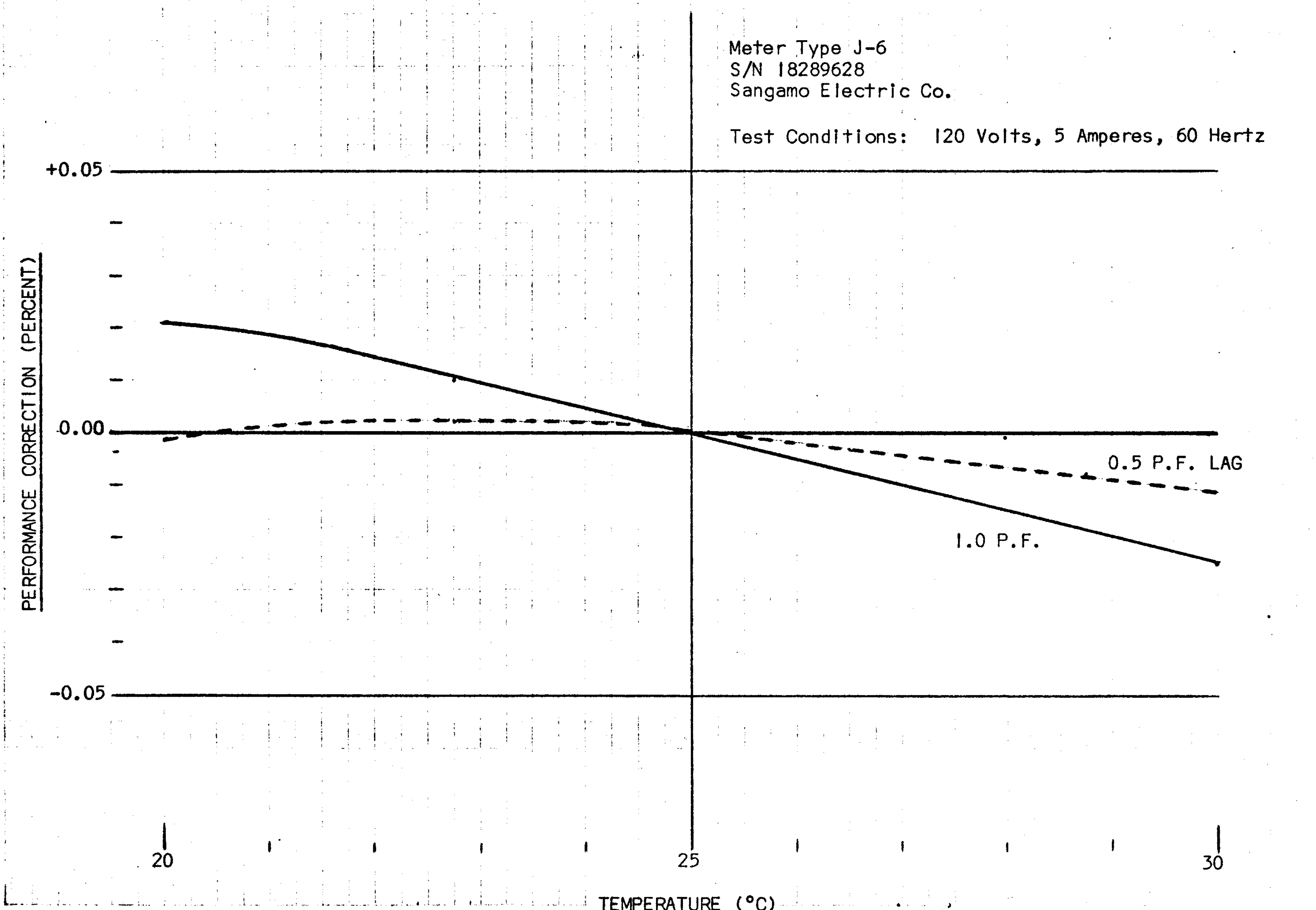


BS-G 48 D
K&E CO. W 2634

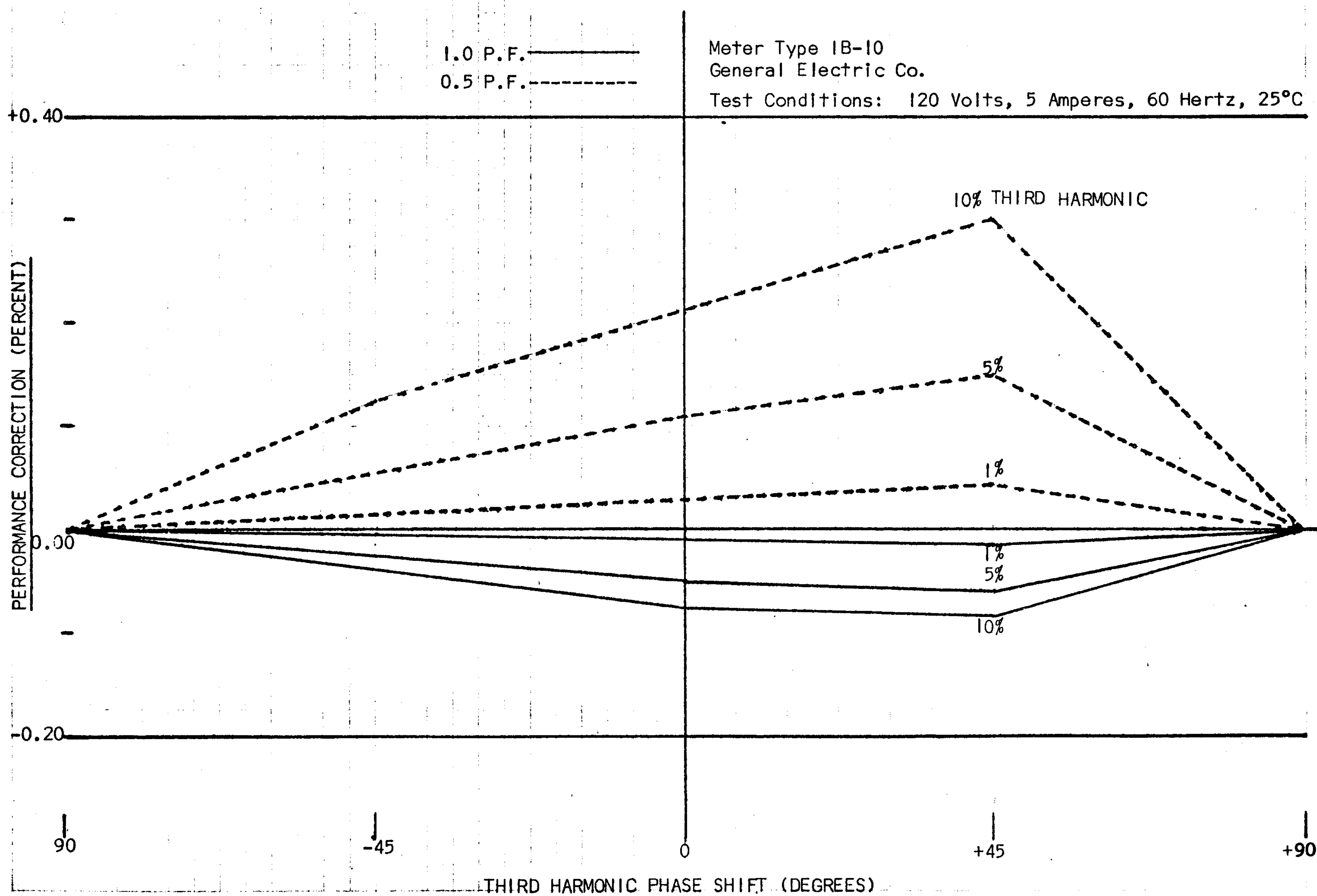
TEMPERATURE CHARACTERISTICS FOR RP106-3



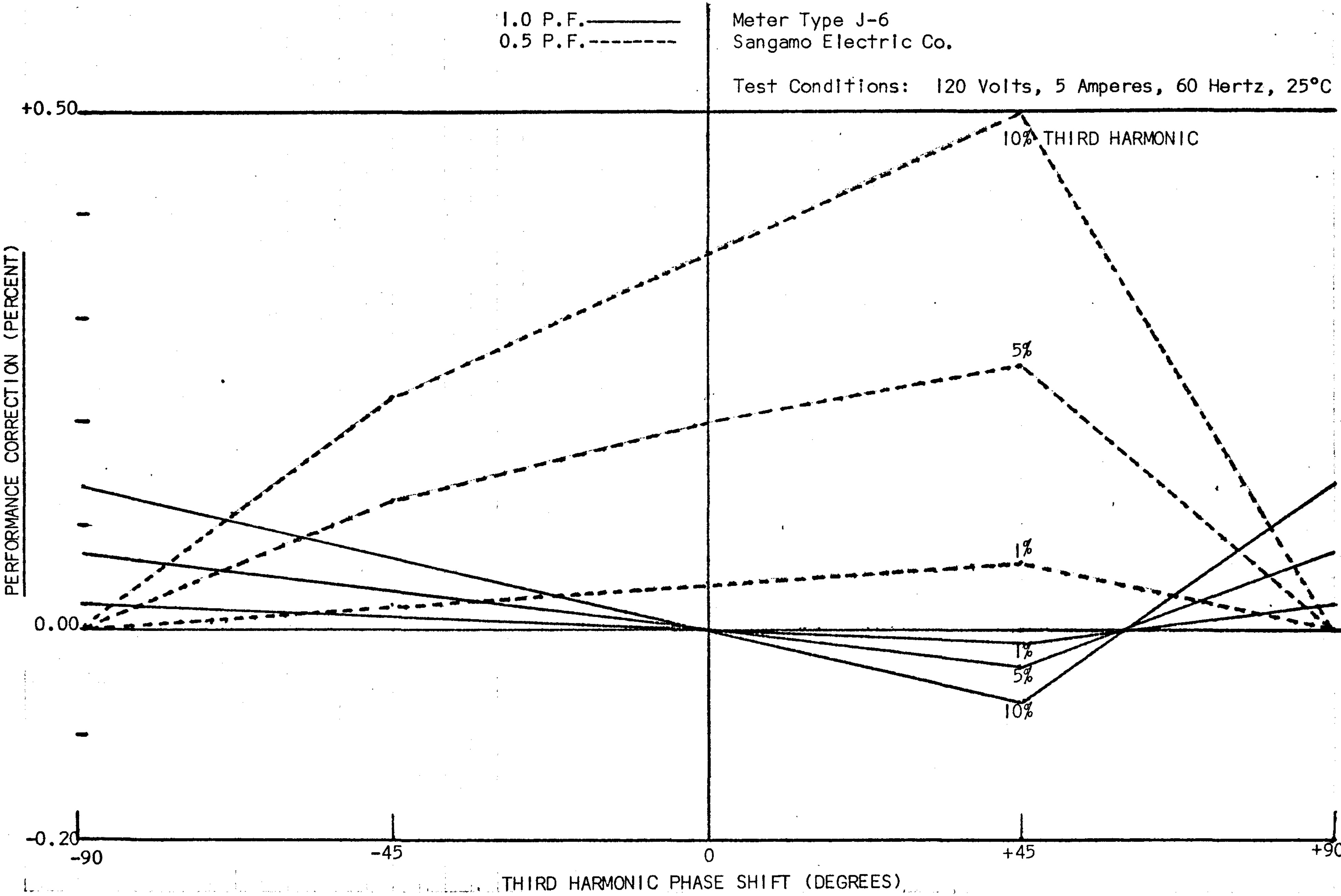
TEMPERATURE CHARACTERISTICS FOR RP106-4



WAVEFORM DISTORTION ANALYSIS
THIRD HARMONIC IN CURRENT ONLY

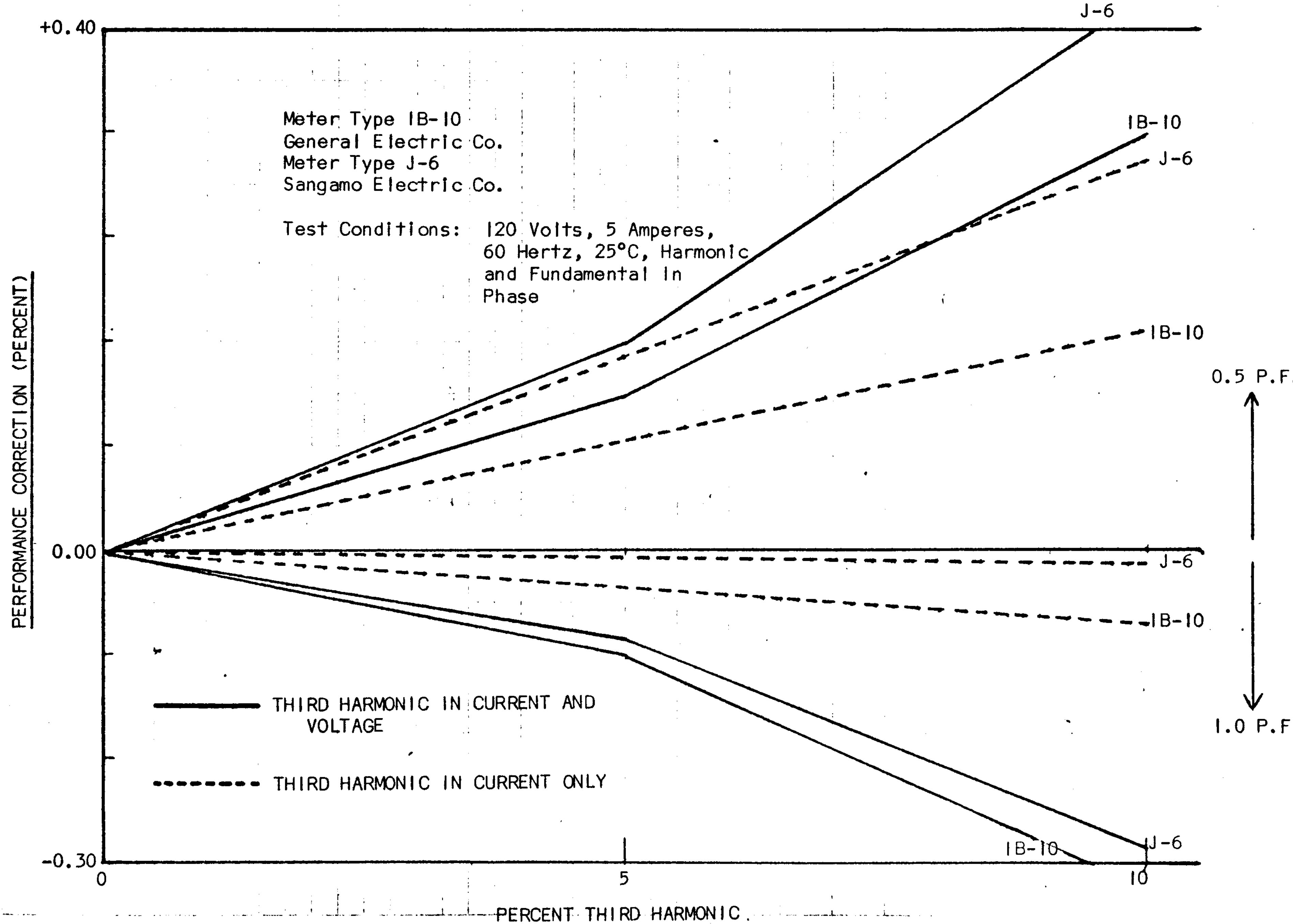


WAVEFORM DISTORTION ANALYSIS
THIRD HARMONIC IN CURRENT ONLY



ES-G 46 B
K&E CO. W 631

WAVEFORM DISTORTION ANALYSIS
THIRD HARMONIC IN CURRENT AND VOLTAGE



APPENDIX D

UNCERTAINTIES IN TRANSFERRING THE UNIT OF ENERGY FROM NBS TO THE RP106 STANDARD METERS 1.0 P.F.

	RP106 STANDARD METER							
	1		2		3		4	
	ε	ε^2	ε	ε^2	ε	ε^2	ε	ε^2
Uncertainties in ac-dc difference of the JEMIC Standard								
Uncertainties in ac-dc difference of standard wattmeter:	0	0	0	0	0	0	0	0
Resolution of standard wattmeter:	35	1225	35	1225	35	1225	35	1225
Resolution of JEMIC Standard:	16	256	16	256	16	256	16	256
Stability of ac power:	20	400	20	400	20	400	20	400
Stability of dc power:	10	100	10	100	10	100	10	100
Uncertainties in dc calibration of the JEMIC Standard								
Resolution of the JEMIC Standard:	16	256	16	256	16	256	16	256
Stability of the dc voltage:	5	25	5	25	5	25	5	25
Stability of the dc current:	5	25	5	25	5	25	5	25
Potentiometer uncertainties:	10	100	10	100	10	100	10	100
Standard cell uncertainties:	10	100	10	100	10	100	10	100
Standard voltbox uncertainties	6	36	6	36	6	36	6	36
Standard shunt uncertainties	10	100	10	100	10	100	10	100
Uncertainties in ac calibration of RP106 Standards								
Voltage uncertainties:	9	81	9	81	1	1	0	0
Current uncertainties:	3	9	2	4	2	4	2	4
Frequency uncertainties:	2	4	2	4	5	25	5	25
Temperature uncertainties:	10	100	10	100	6	36	5	25
Relay timing uncertainties:	6	36	6	36	NA		NA	
Total:	173	2853	172	2848	157	2689	155	2677

UNCERTAINTIES IN TRANSFERRING THE UNIT OF ENERGY FROM NBS TO THE RP106 STANDARD METERS 1.0 P.F.

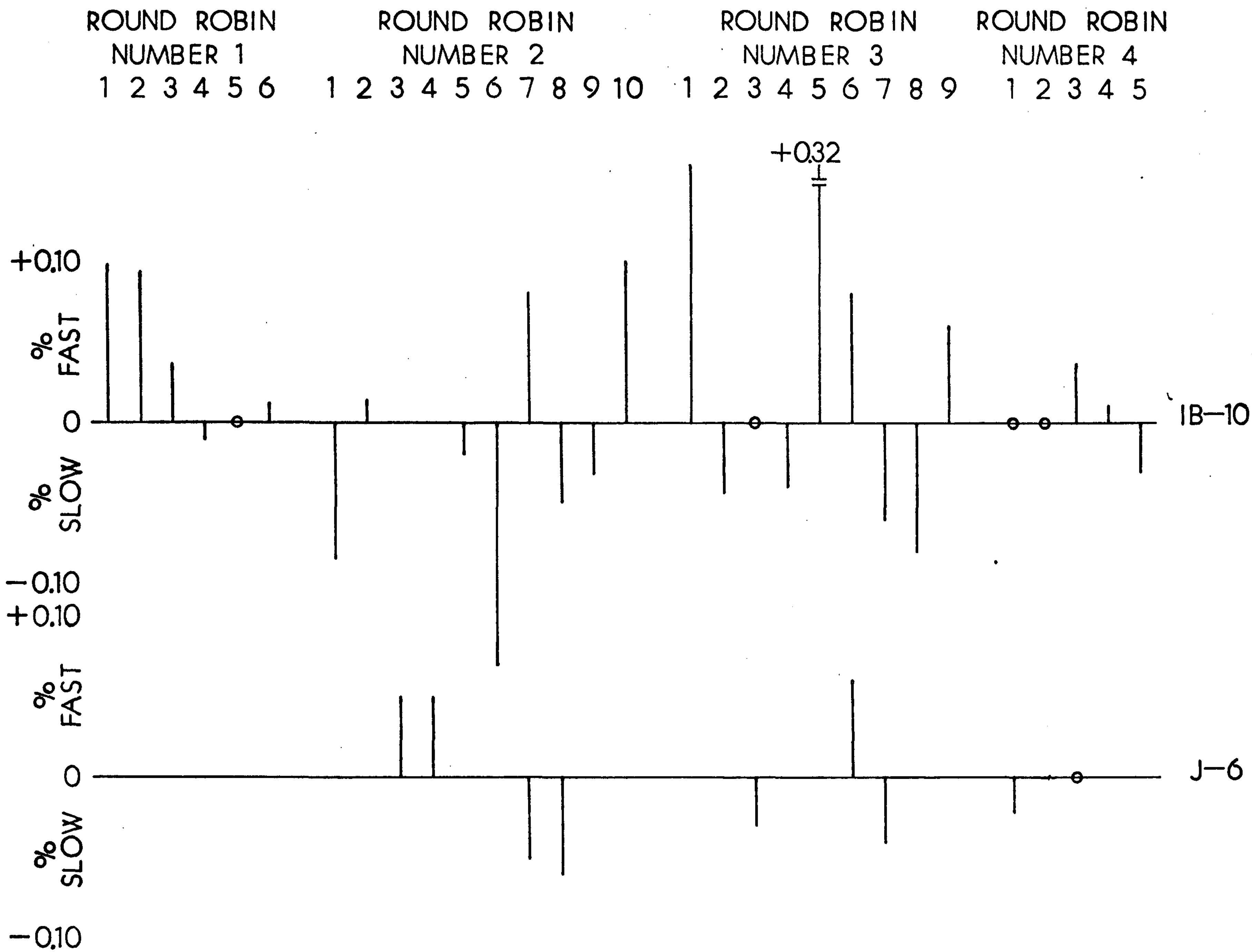
	RP106 STANDARD METER			
	1	2	3	4
Square root of the sum of the squares:	53	53	52	52

UNCERTAINTIES IN TRANSFERRING THE UNIT OF ENERGY FROM NBS TO THE RP106 STANDARD METERS 0.5 P.F.

	RP106 STANDARD METER							
	1		2		3		4	
	ε	ε^2	ε	ε^2	ε	ε^2	ε	ε^2
Uncertainties in ac-dc difference of the JEMIC Standard								
Uncertainties in ac-dc difference of standard wattmeter:	40	1600	40	1600	40	1600	40	1600
Resolution of standard wattmeter:	35	1225	35	1225	35	1225	35	1225
Resolution of JEMIC Standard	32	1024	32	1024	32	1024	32	1024
Stability of ac power:	20	400	20	400	20	400	20	400
Stability of dc power:	15	225	15	225	15	225	15	225
Uncertainties in dc calibration of the JEMIC Standard								
Resolution of the JEMIC Standard:	32	1024	32	1024	32	1024	32	1024
Stability of the dc voltage:	5	25	5	25	5	25	5	25
Stability of the dc current:	10	100	10	100	10	100	10	100
Potentiometer uncertainties:	10	100	10	100	10	100	10	100
Standard cell uncertainties:	10	100	10	100	10	100	10	100
Standard voltbox uncertainties:	6	36	6	36	6	36	6	36
Standard shunt uncertainties:	10	100	10	100	10	100	10	100
Uncertainties in ac calibration of RP106 Standards								
Voltage uncertainties:	6	36	1	1	3	9	0	0
Current uncertainties:	14	196	6	36	6	36	8	64
Frequency uncertainties:	0	0	0	0	5	25	5	25
Temperature uncertainties:	6	36	4	16	4	16	2	8
Relay timing uncertainties:	3	9	3	9	NA		NA	
Total:	254	6236	239	6021	243	6045	240	6056

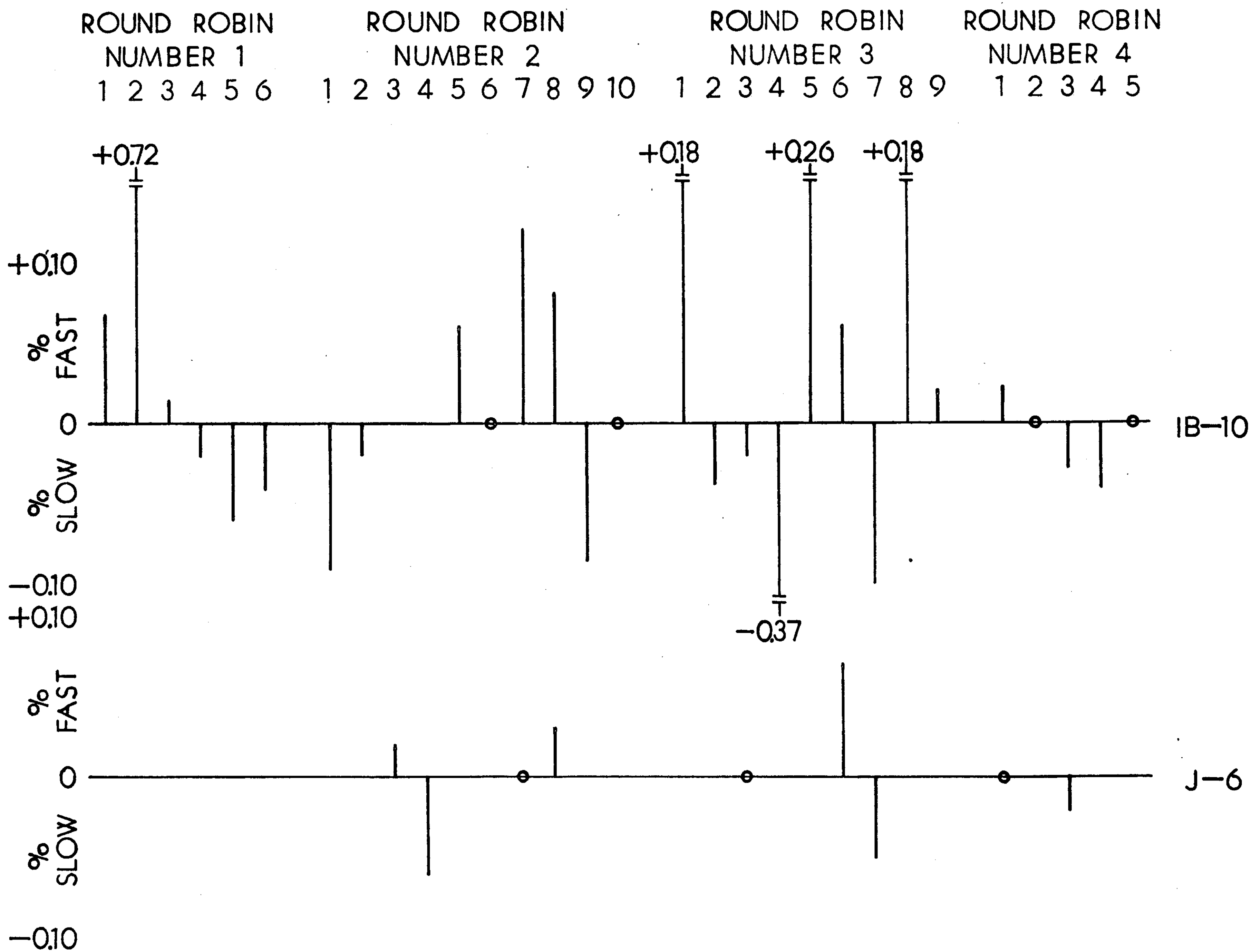
UNCERTAINTIES IN TRANSFERRING THE UNIT OF ENERGY FROM NBS TO THE RP106 STANDARD METERS 0.5 P.F.

	RP106 STANDARD METER			
	1	2	3	4
Square root of the sum of the squares:	79	78	78	77



1.0 P.F.

APPENDIX E


ROUND ROBIN NUMBER 1
1 2 3 4 5 6
ROUND ROBIN NUMBER 2
1 2 3 4 5 6 7 8 9 10
ROUND ROBIN NUMBER 3
1 2 3 4 5 6 7 8 9
ROUND ROBIN NUMBER 4
1 2 3 4 5
+0.72
+0.18
+0.26
+0.18
+0.10
% FAST
0
% SLOW
−0.10
−0.37
IB−10
+0.10
% FAST
0
% SLOW
−0.10
J−6

0.5 P.F.