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WANL-TME-1182

June 3, 1965

Westinghouse Astronuclear Laboratory

NON-NUCLEAR QUALIFICATION TESTING
OF THE IMPROVED MODEL WIANCKO AX-44 ACCELEROMETER

MASTER

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JUN 14 1965

• Mr. J. L. Dooling
NERVA Subcontract Manager
Rocket Engine Operations - Nuclear
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Post Office Box 1947
Sacramento, California

Subject: WANL-TME-1182, "Non-Nuclear Qualification Testing of the
Improved Model Wiancko AX-44 Accelerometer," dated June 3, 1965

Dear Mr. Dooling:

Transmitted herewith are ten (10) copies of the subject report. This
report is transmitted for your information.

Respectfully,

H. F. Faught
Program Manager
NERVA Nuclear Subsystem

Enclosure - 10

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WANL-TME-1182

June 3, 1965

SUBMITTED BY:

Westinghouse Electric Corporation
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Pittsburgh 36, Pennsylvania

NON-NUCLEAR QUALIFICATION TESTING
OF THE IMPROVED MODEL WIANCKO AX-44 ACCELEROMETER

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SUMMARY

This report presents the results of the non-nuclear qualification testing performed on three improved model Wiancko AX-44 variable reluctance accelerometers (WANL Part No. 978D227H02B). These improved models were redesigned internally by the vendor in order to reduce the thermal sensitivity effects experienced with the earlier developmental models (Ref: WANL-TME-1060). In general, it can be stated that the improved models exhibit significantly better performance over the temperature range of -320°F to $+600^{\circ}\text{F}$. Specific performance characteristics are as follows:

1. Linearity and Hysteresis - The combined error resulting from the effects of non-linearity and hysteresis was less than ± 1 per cent of full scale output over the temperature range of -320°F to $+600^{\circ}\text{F}$.
2. Thermal Sensitivity Shift - The thermal sensitivity shift was less than ± 20 per cent of the room temperature value over the temperature range of -320°F to $+600^{\circ}\text{F}$, and was found to be independent of acceleration level.
3. Frequency Response - The frequency response from 15 cps to 200 cps was flat to within ± 4 per cent over the temperature range of -320°F to $+600^{\circ}\text{F}$.
4. Thermal Shock - The percent sensitivity deviation during thermal shock from 75°F to -320°F was less pronounced than for the previously tested developmental units. Furthermore, temperature stabilization occurred in about four minutes as compared to ten minutes for the developmental units. This indicates that the new models have greatly improved internal heat transfer paths--an important factor with regard to dissipating radiation-induced heating.

The three units are scheduled for irradiation testing at the Plum Brook reactor during June 1965 in order to determine their performance characteristics in a high level nuclear environment.

NON-NUCLEAR QUALIFICATION TESTING OF THE IMPROVED MODEL WIANCKO AX-44 ACCELEROMETER

1.0 INTRODUCTION

This interim report describes non-nuclear qualification testing of the improved model Wiancko AX-44 (WANL Part No. 978D227H02B) variable reluctance accelerometer which has been conducted by the WANL Reactor Component Sensor Development Group. It was authorized by project task V-1 of project NE 2460A. The purpose of the work was to determine the non-nuclear performance characteristics of the improved accelerometer prior to nuclear testing and evaluation at the Plum Brook Reactor Facility.

2.0 BACKGROUND HISTORY

This accelerometer specified by WANL-E-675453-B, was first ordered on Purchase Order No. 59-NW-43358 dated June 23, 1964. The purchase order called for nine units (additional units were subsequently ordered) to be shipped by July 17, 1964 in time for installation in the NRX-A3 reactor. The units were intended to measure vibration of the control drums and the core support plate. The selection was based on testing of a previous Wiancko design (Model AX-40) in GTR and on similarity of design to a second generation developmental unit which was evaluated by WANL. During manufacture of the units numerous problems were encountered by Wiancko, particularly with respect to thermal zero and thermal sensitivity shifts. A number of variation requests, which were unacceptable to WANL, were submitted by early October 1964. It was decided at that time that usable transducers would not be delivered in time for installation in the NRX-A3 reactor. Hence, the Wiancko accelerometer was placed in a developmental status.

Wiancko was invited to send representatives to WANL to discuss the problems in depth and a meeting was held in mid-November 1964. WANL assistance was provided through consultations regarding materials, instrumentation, and performance feedback from the prior developmental AX-44 accelerometer tests (Ref: WANL-TME-1060).

A redesign by Wiancko was completed by January 1964. The conventional "E" core was replaced by a "U" core with a coil on each arm in the new design. These coils are connected in series and it was shown that the magnetic potential across the remaining paths was zero for balanced coils. Improvement in dynamic performance was obtained, as will be discussed later, at the expense of additional components and design complexity. This is not to say that all problems were solved by the new design; a significant remaining problem, probably intensified by the new design is that of residual unbalance. This can be resolved mainly by improvement of assembly procedures.

Wiancko has designated at least three structures type AX-44 accelerometers. These structures have little in common other than the outside case. The third generation units discussed in the following paragraphs will be termed Wiancko AX-44 Accelerometer (Improved Type) for identification purposes. Three of the improved units were accepted by WANL after minimal performance testing by Wiancko in order to obtain better knowledge of the transducer performance characteristic through in-house qualification testing and to radiation test the devices without further delay. It was recognized by both Wiancko and WANL that two of the three units were out of specification with respect to residual unbalance, but it was considered expedient to accept the units for the above reasons. Delivery of the three units was staggered, beginning in mid-March 1965.

3.0 SYSTEMS DESCRIPTIONS

3.1 Accelerometers

Three (3) ± 10 g accelerometers, having serial numbers A-20976, A-20977, A-20978 were tested.

3.1.1 Purchase Details: The accelerometers discussed below were purchased under purchase order 59 NW 43358 and made to WANL Drawing 978D227H02. They were specified by Equipment Specification WANL-E-675453-B.

3.1.2 Specification: Reference is made to Equipment Specification WANL-E-675453-B. The specified performance characteristics are listed below for easy reference.

Thermal Sensitivity Shift: Shall not exceed ± 1 per cent per 100 degrees of the full range output at $75^{\circ} \pm 10^{\circ}$ F. Upon return to room temperature from any point within the operating temperature range, the permanent shift shall not exceed ± 0.25 per cent per 100 degrees of the temperature change from which the accelerometer has recovered.

Residual Unbalance: The residual unbalance shall not exceed ± 10 per cent of the full range output at rest with the base down.

Frequency Response: The output shall be flat within 5 per cent with input frequencies from 5 to 200 cps at ± 5 g's, limited to 0.5 inch double amplitude, at $75 \pm 10^{\circ}$ F.

Transverse Sensitivity: The change in indicated acceleration due to vibration in the transverse direction shall not exceed 5 per cent. Preference will be given to accelerometer design not exceeding 2 per cent for this parameter.

Range: The nominal range shall be ± 10 g, unless otherwise specified on the purchase order or specification control drawing.

Sensitivity: Minimum 5 millivolts rms, maximum 1 volt, preferred nominal 100 millivolts; for rated peak to peak g level at rated excitation of 5 volts at 5 kc.

Linearity and Hysteresis: The combined error resulting from the effects of nonlinearity and hysteresis shall not exceed ± 1 per cent of peak to peak output over the operating temperature range. Linearity and hysteresis shall be demonstrated at 40 ± 5 cps and at 100 ± 5 cps during acceptance testing.

Repeatability: The output shall be repeatable within 0.5 per cent for three consecutive full range excursions performed under identical conditions at the 100 ± 5 cps test condition over the operating temperature range.

Operating Temperature Range: The accelerometer shall be operable within the limits of accuracy specified herein from -320°F to $+600^{\circ}\text{F}$. (Test temperatures shall be $\pm 25^{\circ}$ from the preceeding temperatures.)

Thermal Zero Shift: Shall not exceed ± 1 per cent per 100 degrees of the full range output at $75^{\circ} \pm 10^{\circ}\text{F}$. Upon return to room temperature from any point within the operating temperature range, the accelerometer shall not exhibit permanent shift outside the limit of the specified residual unbalance and not exceed ± 0.25 per cent per 100 degrees of the temperature change from which the accelerometer has recovered.

Acoustic Noise: The performance of the accelerometer shall be within the limits of this specification at a noise level of 150 db when tested in accordance with MIL-STD-810 (or MIL-STD-446 at vendor's option). Sound level may be applied broadband with a random gaussian distribution.

Ambient Pressure: The accelerometer shall be operable within the limits of this specification when subjected to an external pressure of 0 to 1000 psia.

Shock: A 25 g shock pulse of seven milliseconds total duration shall not cause a shift in performance outside the limits of this specification.

Humidity: Subjection of an external 0 to 100 per cent relative humidity shall not cause a shift in performance outside the limits of this specification. This shall be tested by immersion in water pressurized to 200 psi.

Natural Frequency: The natural frequency of the accelerometer shall be at least 1000 cps.

Ambient Temperature Range: The performance of the accelerometer shall be within the limits of this specification when tested at $75 \pm 10^{\circ}\text{F}$ after it is held at -423°F for one hour and also after it is held at $+750^{\circ}\text{F}$ for one hour.

Resolution: A change in measurand as small as 0.1 per cent of the full range measurand shall produce a recognizable change in output.

3.1.3 Mechanical Details: The transducer unit consists of a mass loaded taut diaphragm which moves under inertial forces between two magnetic cores. Mu metal pads, welded to the mass, complete the magnetic circuits. The Ni Span C diaphragm is .004 inches thick; full scale displacement of the mass is 60 microinches. The case material is 347 stainless steel. Integral MgO insulated sheathed signal cables are provided. The magnetic circuit of this improved type was completely redesigned; the diaphragm assembly and outside case of the Developmental AX-44 was retained. In the new design "U" type laminated mu metal cores are employed with two series-connected coils per core for a total of four coils per transducer.

3.1.4 Electrical Details: Flux leakage paths through the coil bracket and case are eliminated, provided the coils are balanced, by the four coil configuration. These coils consist of approximately 200 turns of No. 38 nickel clad copper wire. The nominal inductance is 4 millihenries per coil set which is matched to within .05 millihenries. The nominal air gap is .002 inches wide. The units are designed for 5 volts rms, 5 kcs, excitation.

3.2 Measurement Systems

3.2.1 Dynamic Test Set: Details of the dynamic test set are shown in a single line diagram by Figure 2. The data indicated by the figure were monitored and recorded at each data run. A computer program was written and the acquired data were machine plotted at the East Pittsburgh Division of Westinghouse. About 25 curves per unit were so prepared; selected typical curves will be presented in the following sections. Unit SN A20976 was neither the best or the poorest of the three units and was therefore

considered "typical" of the design. All of the curves which are shown, except two which are identified later, were plotted from SN A20976 data. The remaining curves are available to interested persons. It will be observed that point-to-point plotting (no smoothing) was employed.

The accuracy of the dynamic test set is estimated to be 4.3 per cent, worst case.

Shaker Calibration	3.0 per cent
Effect of Mounting Extension	3.0 per cent
Instrumentation, Other	1.0 per cent
<hr/>	
Accuracy, Worst Case	4.3 per cent

3.2.2 Static Test Set: Resistance, inductance, and capacity measurements were made by use of the General Radio Type 1650A impedance bridge. Accuracy of the static measurements were essentially that of the bridge, namely: Resistance ± 1 per cent ± 10 milliohms, Inductance ± 1 per cent $\pm 1 \mu h$, and Capacity ± 1 per cent ± 1 pf.

4.0 THERMAL CHARACTERISTICS

4.1 Computed: A radiation heating analysis of the accelerometer was made by the WANL Radiation Effects Program Department using the TOSS (Transient or Steady State) computer code. The result of this work is shown by Figure 1 and Graph 1. The computer internal temperatures, generated by 3 watts per gram radiation heating with the transducer case held to $+150^{\circ}F$, are shown on the model of Figure 1. In the graph, computed coil and core temperatures are shown as functions of heat generation for $150^{\circ}F$ transducer case temperature.

4.2 Measured: Measured thermal characteristics will be discussed under the individual test descriptions.

5.0 NON-NUCLEAR QUALIFICATION TESTS

The static tests to be described consisted of a check of hermetic seal and measurement of coil resistance, inductance, insulation resistance and coil to case capacity at -320° , 75° , 200° , 400° , and $600^{\circ}F$. The dynamic tests consisted of measurement of linearity and frequency response at the above temperatures. Sensitivity as a function of temperature was measured and recorded during change of test temperature. In addition, sensitivity was measured as a function of time and of temperature during temperature shock from 75° to $-320^{\circ}F$. Transverse response was measured at room temperature.

6.0 STATIC TEST RESULTS

6.1 Hermetic Seal: The units were mounted inside a pressure chamber and pressurized with helium at 200 psi for 30 minutes. The units were then removed and probed for helium leakage. Leakage, at a weld, was observed in serial number A-20976. The unit was satisfactorily re-welded in-house.

6.2 Coil Resistance: Coil resistance was measured at several temperatures within the -320° to $+600^{\circ}$ F temperature range. The end-to-end coil resistance, within the above temperature range is described by equation (1).

$$\begin{aligned} R &= 8.125 \times 10^{-2} T + 38.75 \text{ (ohms)} \\ \text{where } R &= \text{end-to-end coil resistance in ohms} \\ T &= \text{temperature in } ^{\circ}\text{F.} \end{aligned} \tag{1}$$

The center conductor of the sheathed cable employed is nickel clad copper while the outer conductors are copper. This configuration prevents the measurement of individual coil parameters since an active cu-ni thermocouple is introduced in series with the center tap. The thermocouple does not exist in the outer leads, therefore, end-to-end coil parameters were measured.

6.3 Coil Inductance: Coil inductance was measured at several temperatures. The nominal 8 millihenries dropped off by 7 per cent at $+600^{\circ}$ F.

6.4 Insulation Resistance: The lowest insulation resistance observed at 50 volts DC was 16 megohms at 600° F. This was measured in SN A20978.

6.5 Coil to Case Capacity: The typical coil to case capacity was 10,000 pf. (Included was 15 feet sheathed lead.) This value changed by less than 2 per cent over the -320° to $+600^{\circ}$ F temperature range.

6.6 Residual Unbalance: Residual unbalance (static output with zero input) is perhaps the greatest shortcoming of this accelerometer design. During fabrication, the transducer coils are welded to the frame, and although well matched coils are used, the welding step will generally destroy the initial balance in a random manner. Unbalanced units are then disassembled and hand lapped, several times in some cases, to restore balance after weld. As well as can be determined, this appears to be the only Wiancko process step which is not well controlled. Measured unbalance, at room temperature, for the three units tested are listed in Table I.

TABLE IResidual Unbalance Wiancko AX-44 (Improved Type)

<u>Unit</u>	<u>Residual Unbalance % FR</u>
A20976	2,200
A20977	260
A20978	4,400

While the data acquisition equipment following the demodulator can be AC coupled thus discarding the unbalance voltage, the unbalance is undesirable since the demodulator must be scaled to accept the high level input.

7.0 DYNAMIC TESTS RESULTS

7.1 Transverse Sensitivity: The transverse response, at room temperature, was 2.5 per cent at 40 cps and 2.7 per cent at 100 cps test frequencies.

7.2 Linearity: Graphs 2, 3, 4, 5, and 6 are computer plots of SN A20976 linearity data, measured at 100 cps, within the -320° to $+600^{\circ}$ F temperature range. Linearity plots at 40 cps were similar to the plots at 100 cps. The output voltages which are labeled DC volts on the curves were obtained from an AC-DC converter. They were inadvertently marked DC volts rather than rms volts.

7.3 Hysteresis: Reference to the linearity plots indicates that hysteresis is virtually zero.

7.4 Frequency Response: Graphs 7 through 11 are computer plots of SN 20976 frequency responses at temperatures within the -320° to $+600^{\circ}$ F range. The curves were plotted with the 100 cps output as the reference point. The specified upper frequency of the accelerometer is 200 cps; however, since performance was acceptable above this level, the units were tested to 500 cps as is indicated by the curves. The responses of SN A20977 and SN A20978 were similar.

7.5 Relative Output vs. Temperature: Graph 12 is a plot of percent full scale output versus temperature of SN A20976. The graphs for 40, 100, and 200 cycles per second were plotted utilizing the output at 100 cps and 75° F as the 100 per cent reference point.

The linear decrease in sensitivity with temperature is probably caused by three factors: (1) Linear increase in coil resistance with temperature, (2) magnetic property variation of the "U" core material with temperature, and (3) stiffening of the diaphragm with decrease in temperature.

7.6 Percent Deviation vs. Temperature: Graph 13 is a plot of percent deviation versus temperature for a family of "g" curves at a constant frequency of 100 cycles per second. The curves were plotted utilizing the output at 75°F and the corresponding "g" level as the reference point. The percent deviation for the selected acceleration levels is within ± 20 per cent from LN₂ to 600°F and the slope of the curves are similar with respect to each other indicating that the temperature sensitivity effect is essentially independent of acceleration level.

7.7 Temperature Gradient Test: The units were vibrated at half range (5 g's) at 100 cps at room temperature. They were then suddenly immersed in liquid nitrogen. The vibration was held constant and the outputs were monitored. Graphs 14, 15, and 16 are computed plots which show relative sensitivity of the three units versus time in the liquid nitrogen.

During the first part of the test a temperature gradient approaching 400°F was generated between the accelerometer case and the internal components. Operation in a cold gas with radiation heating was thus simulated. Sensitivity was higher than normal at this time. It is postulated that during this part of the test the diaphragm frame was shrinking faster than the diaphragm. The equivalent stiffness of the system decreased and the sensitivity increased. Temperature gradients generated by radiation heating would be expected to cause similar increases in sensitivity. It is noteworthy that stabilization occurred in about four minutes in the improved accelerometer. Stabilization time of the developmental AX-44 was approximately ten minutes in a similar test. The thermal conductivity of the improved structure has been significantly increased.

7.8 Additional Non-Nuclear Tests Required: The following tests, not yet performed in order to avoid possible damage to the only samples available for radiation testing, are required to complete non-nuclear qualification: Acoustic Noise; Ambient Pressure to 1000 psia; Shock; and storage at -423°F and +750°F. These tests will be conducted by the vendor.

7.9 Nuclear Tests: Nuclear evaluation will be made in Test 23/W006 during June 1965 at Plum Brook. This test is designed to: (a) Determine experimentally temperature rise as a function of radiation heating rate; (b) expose the samples to an

integrated fast neutron dose equivalent to that obtained in a one hour full power run in a specific NRX application, and (c) to experimentally determine operational or damage thresholds. Figure 3 is a photograph of the accelerometers in the Plum Brook test fixture.

8.0 COMPLIANCE TO SPECIFICATION

8.1 Thermal Sensitivity Shift: The measured sensitivity shift is of the order of 3 per cent per 100°F.

8.2 Residual Unbalance: The measured residual unbalance is far in excess of the specified ± 10 per cent of full range.

8.3 Other Requirements: Other requirements of the specification, which were tested to, were within the specified limits.

9.0 CONCLUSIONS

9.1 Specification Requirements: The specified thermal sensitivity shifts and residual unbalances were not obtained. In NRX application, large temperature gradients will exist across the transducer during operation due to radiation heating. The specification does not take this into account. Therefore, the transducer should not be disqualified on the basis of greater than specified thermal sensitivity shift at this time. The temperature gradient in combination with a given ambient temperature must be taken into account.

The uncontrolled residual unbalance is a more serious problem. The manufacturer is presently investigating a method of decreasing the percentage full scale unbalance by increasing the transducer sensitivity. Units incorporating this feature will be delivered by June 30, 1965. The swamping of the unbalance is a stop-gap measure rather than a solution to the basic assembly and/or design problem. The unbalance can be electronically compensated in dynamic application of the transducer. It is to WANL's advantage to relax this requirement at this time because the transducer is well advanced in other respects.

9.2 Radiation Resistance: The performance characteristic of the transducer in high level radiation will be determined in the forthcoming Plum Brook test.

9.3 NRX Application: A linear scale up of the computed temperature rise in the transducer for 3 watts/gram radiation heating gives a 900°F temperature rise at 4 watts/gram internal heating. In the NRX applications heat sinking will be better than that used in the calculation. This will reduce the temperature rise and change the temperature distribution from that of the calculation. Also, while the transducer is rated

at 600°F maximum operating temperature, the limiting factor is the curie temperature of the mu metal core. This temperature is 806°F. The transducer will probably operate at temperatures in excess of 700°F. Based on the heat transfer analysis, the temperature gradient test, and the above considerations it is estimated that, as far as temperature is concerned, the transducer will operate, with sensitivity increased over room temperature sensitivity by perhaps 25 per cent, in an environment of -200°F ambient temperature and 4 watts/gram radiation heating. The radiation test is required to determine operational characteristics in radiation and to determine whether or not the above conclusion is correct.

Calculated Internal Temperatures
of Wiancko AX-44 Accelerometer
Type A3

Heat Generation - 3.0 watts/gram

Helium Filled

Water Coolant - 150°F

FIGURE I

FIGURE 2
ELECTRICAL SINGLE LINE
ACCELEROMETER DYNAMIC
TEST SET

FIGURE 3
WIANCKO ACCELEROMETERS MOUNTED IN IRRADIATION TEST 23/W006 FIXTURE (MARCH, 1965)

GRAPH 1

Calculated Maximum Internal Temperature
for Wiancko Accelerometer AX-44 Type A3
for various heat generation rates

Coolant Temperature - 150°F

GRAPH 2

LINEARITY
AT -320°F , 100 cps
WIANCKO AX-44
SN A20976

MARCH 1965

GRAPH 3

LINEARITY
AT 75°F, 100 cps
WIANCKO AX-44
SN A20976

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GRAPH 4

LINEARITY
AT 200°F, 100 cps
WIANCKO AX-44
SN A20976

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GRAPH 5

LINEARITY

AT 400°F, 100 cps

WIANCKO AX-44

SN A20976

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GRAPH 6

LINEARITY
AT 600°F, 100 cps
WIANCKO AX-44
SN A20976

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GRAPH 7

FREQUENCY RESPONSE

AT -320°F, 5 g's.

WIANCKO AX-44

SN A20976

MARCH 1965

GRAPH 8

FREQUENCY RESPONSE

AT 75°F, 5 g's

WIANCKO AX-44

SN A20976

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GRAPH 9

FREQUENCY RESPONSE
AT 200°F, 5 g's
WIANCKO AX-44
SN A20976

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GRAPH 10

FREQUENCY RESPONSE

AT 400°F, 5 g's

WIANCKO AX-44

SN A20976

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GRAPH 11

FREQUENCY RESPONSE
AT 600°F, 5 g's
WIANCKO AX-44
SN A20976

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GRAPH 13

PERCENT DEVIATION
vs.
TEMPERATURE
WIANCKO AX-44
SN A 20976

GRAPH 14

TEMPERATURE SHOCK
FROM 75°F to -320°F
RELATIVE SENSITIVITY (at 5 g's, 100 cps) vs. TIME
WIANCKO AX-44
SN A20976

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GRAPH 15

TEMPERATURE SHOCK
FROM 75°F to -320°F
RELATIVE SENSITIVITY (at 5 g's, 100 cps) vs. TIME
WIANCKO AX-44
SN A20977

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GRAPH 16

TEMPERATURE SHOCK
FROM 75°F to -320°F
RELATIVE SENSITIVITY (at 5 g's, 100 cps) vs. TIME
WIANCKO AX-44
SN A20978

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