THE STANDARDIZATION OF FREQUENCES IN POWER SYSTEMS BY AUTOMATIC CONTROL

by

Howard M.Patterson

and

C.T.Nunley,Jr.

A THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

ELECTRICAL ENGINEERING COURSE

The University of Tennessee

1932

F O R E W O R D

We wish to take this opportunity to express our appreciation to the Tennessee Public Service Company and to the Tennessee Electric Power Company for their cooperation in providing us with certain necessary apparatus.

H. M. P.

C. T. N.

TABLE OF CONTENTS

	Page
INTRODUCTION	1-2
GENERAL SURVEY OF FIELD	3-6
PURPOSE	7-8
DESCRIPTION OF METHOD AND APPARATUS USED	9-18
CONCLUSIONS	19

INTRODUCTION

Before the beginning of the twentieth century there were a few engineers who realized the possibility that commercial alternating current might be used in some manner to measure time: but as everything else people failed to accept such a theory and the engineers' dreams did not materialize until quite a few years later

Up to 1916 there was no commercial alternating-current system in existence in which generator speed was regulated with sufficient accuracy so that the current could be used in indicating time through some indicating device utilizing the variations of the alternating current to record time.

One finds the need of accurately regulated frequency for alternating-current systems in the modern plan of interconnections. The extremely large growth in the demand for power in the last few years has made it necessary for the various power companies to extend their lines and increase their generating capacities in order to cope with the increase in demand for power. At times some of the companies' stations are not able to carry the excess load applied at certain hours during the day and on the other hand there may be times when the load is not great enough to require the operation of all the units.Another important factor is found in the fact that there is a possibility that the service might be interrupted by some disturbance. All these factors help to make up the conditions which make it necessary for some means to be

found that will give the greatest system efficiency and at the same time will require the minimum amount of operating costs with the least possibility of interruptions in service. This demand was answered by the plan of interconnections between power companies. In order for the companies to interconnect their frequency must be the same that the two systems might be synchronized, which fact necessitates the standardizing of the frequency at each of the companies' generating plants.

This standardization of frequencies is a complicated operation since the operators have to keep a constant lookout for variations in the frequency and adjust the control of the generators accordingly. Many devices for the control of frequencies are now in the process of developement but as yet none of them have been found to be practical enough to justify their being placed on the market.

In presenting this thesis the authors hope to furnish a reasonable means of controlling automatically the frequency of a power generating station with the least possible error. It has long been necessary for the operators to watch the instruments and consequently adjust the governors controlling the generators. The device here presented, if found practical and can be developed, will do away with the operators' constant vigil and automatically control the governors of the generators which likewise controls the speed and the frequency of the system.

GENERAL SURVEY OF FIELD

In 1916 two devices were brought out which in the succeeding years made possible commercial alternating-current time service.

The first of these devices was a self-starting synchronous motor utilizing residual magnetism to permit a rotor to start and run at synchronous speed. This type of motor differs from all the common forms of alternating-current motors in that eddy currents induced either in the mass of the rotor or in some form of winding upon the rotor are not utilized to start the rotor from rest. Instead, the rotor is made of such permanent magnetic material and is so proportioned with respect to the field that remanent magnetic poles are set up in the rotor material by the alternating-current magnetism of the field in such a manner as to cause the desired motion. Such a motor is sometimes known as a hysteresis motor.

The second device consisted of an indicating instrument that would show to a generating station operator directly in terms of time, deviations of the average system frequency from the standard. By noticing the instrument an operator could so adjust the speed of the generator as to maintain such small deviations from the standard average that the alterations could be used to measure time for all ordinary commercial purposes. Fig.1 shows the dials of a type of master clock which is in common use. The large dial in the center has two hands, one black and the other gold. The black hand

makes one revolution on the dial every five minutes, its rate of motion being regulated by an accurately adjusted pendulum beating seconds. The gold hand is driven by a gear train directly from one of the self-starting synchronous motors. The gear ratio is such that when the average frequency is correct this hand will also make one revolution in exactly five minutes.[1]

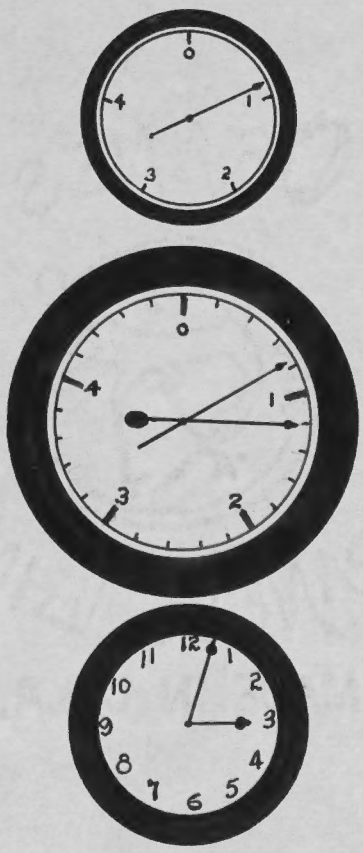


Fig. 1

1. H.E.Warren," Synchronous Electric Time Service", Electrical Engineering,April '32, 228-231

The hands are started off together, and so long as the average frequency remains correct, will keep together with no visible angle between them. An error in the average frequency will cause the gold hand to move slightly slower or faster than the black hand and they will become separated. The angle of separation will be a direct visible measure of the error in the frequency of the system. If the gold hand is ahead, this will show that the system time is fast; if behind, that it is slow.

An error in the average frequency as small as one sixtieth of a cycle will cause a differance of one second between the hands of the master clock in one hour. If such an error continues, the spread will continue to increase as time passes. When carefully regulated this is better than one second per day or an absolute precision of about one part in one hundred thousand.

When the operator at the generating station which is regulating frequency adjusts the turbine governors from time to time so as to keep the black hand and the gold hand of the master clock together, he automatically causes all other synchronous motor clocks on the same system to keep correct time. Before master clocks were available, the inherent errors in frequency indicators were sufficient to handicap operators on interconnected systems in their efforts to equalize the frequency preparatory to synchronizing the time systems.[1]

Governor adjustment is necessary in most all plants of the interconnected systems and much is being done at the present to get a device which will automatically control the

1. Ibid, 229

frequency and will supplement the master clocks. When perfected and applied, this device probably will reduce the system time error to such insignificant values as one or two seconds.

PURPOSE

The University of Tennessee owns and operates the power plant which supplies the various buildings on the campus. The problem of constant frequency, as in many other systems, has become more acute each year especially since there is so much need of standard frequency for clocks and other instruments utilizing the alternations of the current in time recording.

In order to determine the average frequency and also study the variations of the frequency over a period of time a recording frequency meter was connected into the system and the time sheet was placed at the exact time of day. Along side this meter was placed an electric clock which records time by the use of the synchronous clock motor. The clock being set ~~set~~ at the correct time and with its source of supply from the University power plant, both instruments were started and allowed to run without interruption for almost four days.

The time of starting was 2 P.M. Tuesday afternoon and they were disconnected from the system at 11:05 A.M. Saturday morning. At the time of disconnection the electric clock showed the time as 11:35 A.M. or thirty minutes faster than the standard time. With a gain of thirty minutes over the period named, the gain for one day would be 7.75 minutes. There being 1,440 minutes in one day, the per cent increase in the electric in one day would be 7.75/1,440 or 0.54 % . If the standard frequency is sixty cycles, the average

frequency at which the system operates 60 x 100.54% or 60.33 cycles.

In Fig.2 is shown a small portion of the variation in frequency as recorded by the frequency meter. With such large variations in frequency a synchronous motor could not be used on commercial time service and the problem of the standardization of frequency presents itself here as well in all other plants and systems.

In working out this thesis it is the ententions of the authors to build a device which will automatically adjust the governors of the turbines and in turn adjust the speed and frequency of the generators.

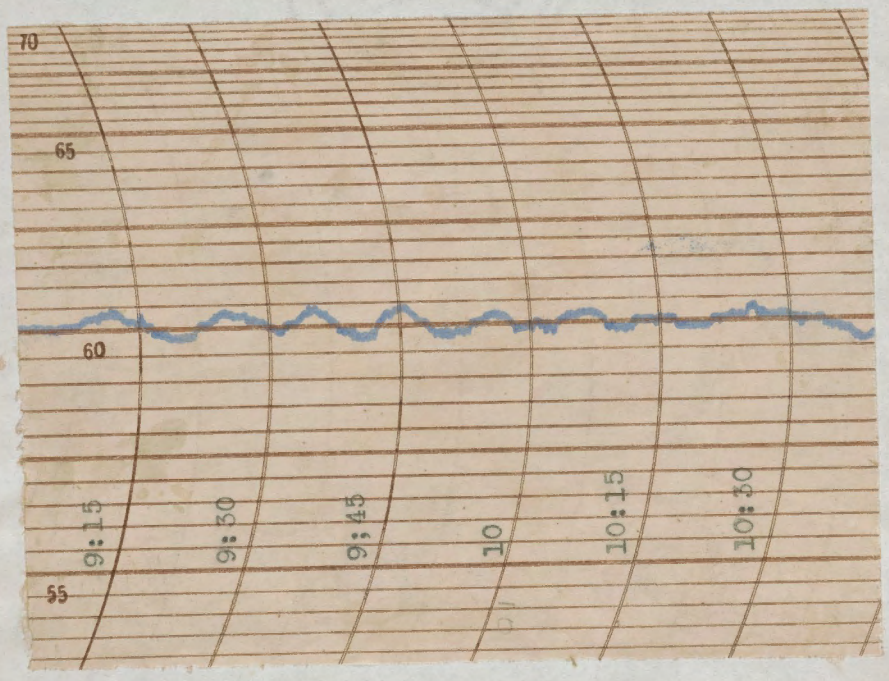


Fig. 2

DESCRIPTION OF METHOD AND APPARATUS USED

On the switch board at the University power plant are connections for a source of supply from the lines of the Tennessee Public Service Company. This supply is fairly constant and may be considered as a standard at sixty cycles.

By using two synchronous clock motors, one connected to the University supply and the other connected to the standard supply, and connecting them together through a universal in such a way that the two motors will rotate oppositely with referance to each other, a pendulum may be suspended from the universal and made to form a contact between a double field reversible direct-current motor and the source of supply. The fields are so wound and connected that when a potential is applied to one of them the motor will rotate in one direction and when the potential is applied to the other the motor will rotate in the opposite direction. In rotating in one direction the motor will operate the gear train to open the governors and in rotating in the other direction the motor will cause the governors to close. This proceedure will increase or decrease the generator speed depending on the condition of the frequency.

The synchronous motors suitable for use in any instruments utilizing the time element are divided into two classes; non-self-starting and self-starting.

Fig.3 shows one kind of non-self-starting motor. There are several kinds of these but they generally have toothed,

soft-steel rotors. The usual stator construction is bipolar with teeth on each pole corresponding to the spacing of the rotor poles. This type of motor would not fit into the operation because of the fact that should the supply on either motor be interrupted the motor would not resume its rotation without the assistance of someone in starting it.

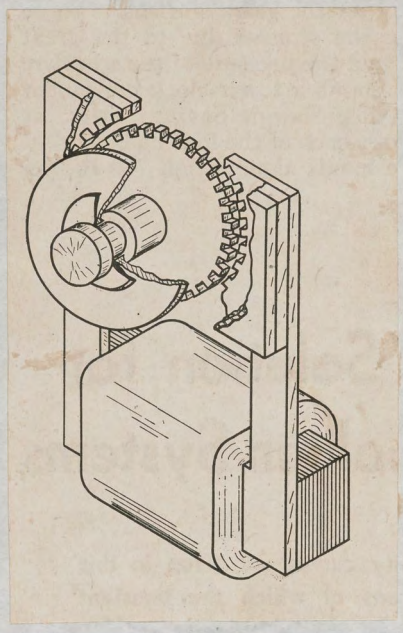


FIG. 3

The self-starting motors which have appeared in the last few years utilize alternating-current fields with rotating components brought about by use of shading coils. Most of these motors have multi-polar rotors with some form of squirrel-cage winding or a copper element wherein Foucault currents are induced by the rotating field. Like ordinary induction motors, such motors get their starting torque through the reaction of

the Foucault currents in the field. One variety of the recent self-starting synchronous motors utilize the residual magnetism for starting and for synchronous operation.[1]

Fig. 4 is a view of a recent model of the Telechron self-starting synchronous clock motor. This is the type of clock motor used in the device for automatically regulating the frequency of power systems.

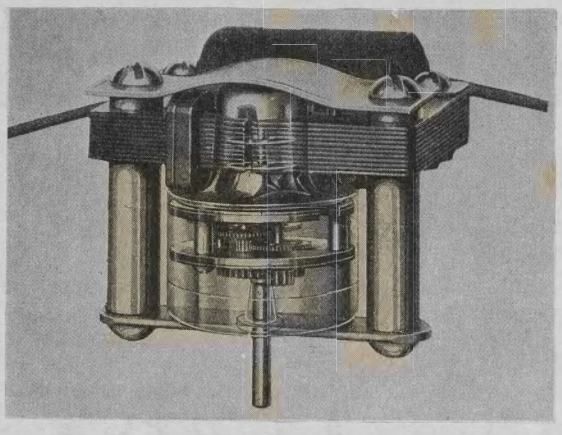


FIG. 4

This type of synchronous motor operates on the principle of residual magnetism as explained above. The rotor turns at a speed of thirty-six hundred revolutions per minute and with a desired speed of one revolution per minute the system of gears must take up the ratio of thirty-six hundred to one.

The power output of the various motors ranges from less than one-millionth of a horsepower to more than one ten-thousandth of a horsepower. The power output of these motors

1. Ibid, p. 230

seems exceedindly small; neverless it is fully adequate for operation required of it in this mechanism.

The electric input to these motors is generally about two watts, but since the power factor is low, the voltamperes vary from four to six. The efficiency of these motors is very low, amounting to a fraction of one per cent. However, the power used is so little that this is of minor importance.

Fig. 5 shows the complete diagram of connections for the Automatic Frequency Control Device.

S_1 is the standard or Tennessee Public Service Company supply, S_2 being the University power plant supply. M_1 and M_2 are the two Telechron self-starting synchronous clock motors, M_1 being connected with the standard supply and M_2 is connected to the University supply. U, is the universal and P, the pendulum connected to the universal. (This portion of the apparatus is viewed from the left side). The motors are so connected through the universal that when both motors are operating at the same speed the pendulum will hang perpendicular. However, when M_2 gets faster than M_1 the pendulum will swing to the left and make contact with C_2. (C_1 and C_2 are two copper strips along which the pendulum may slide) This contacting closes the circuit between the direct-current supply and the governor control motor, G. When the contact at C_2 is made current flows through the closed switch at (a) and into the field of the motor which drives it forward and closes the governor, likewise decreasing the speed of the generator and the frequency of the system. The synchronous motor M_2 will

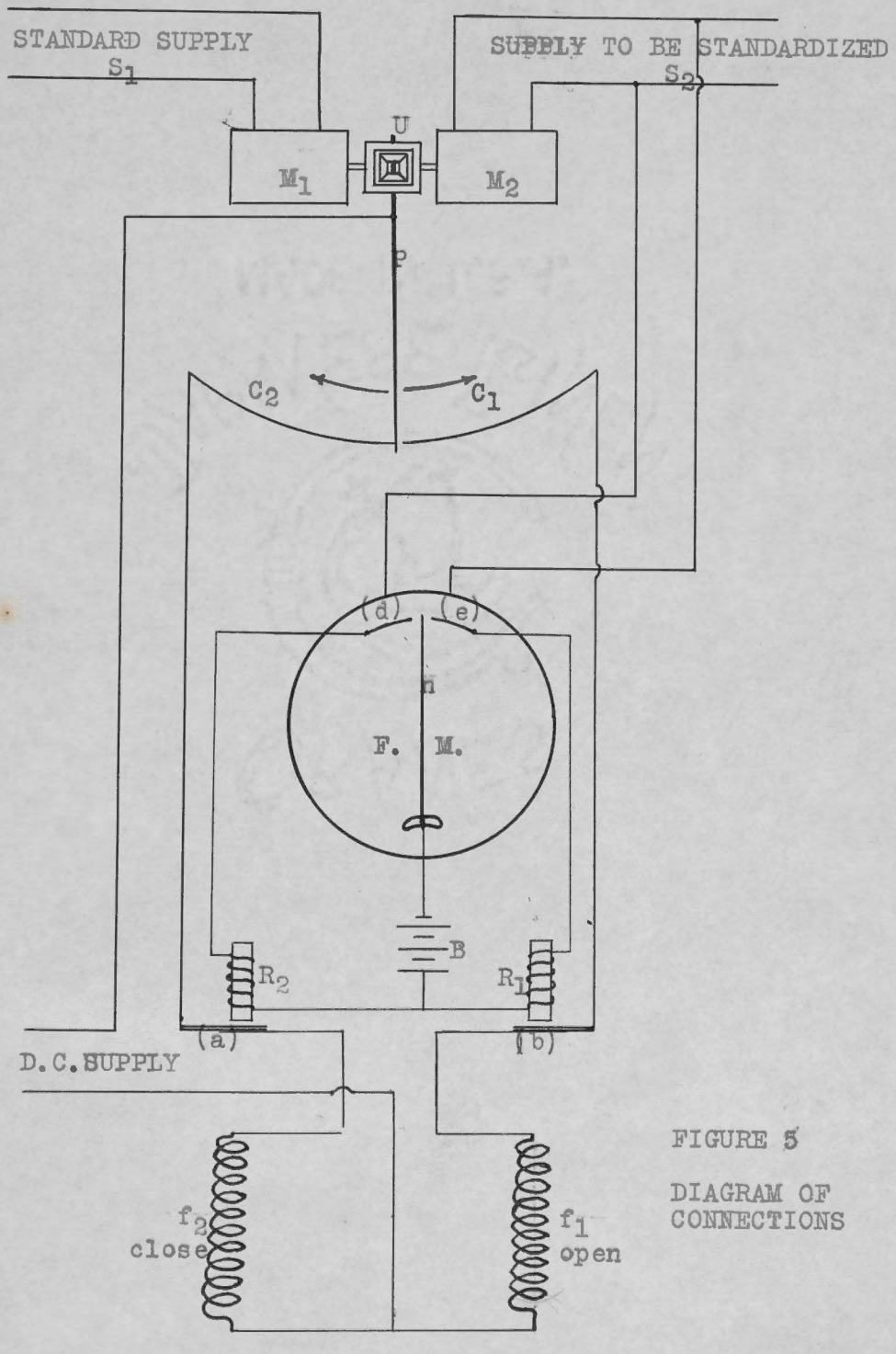


FIGURE 5

DIAGRAM OF CONNECTIONS

be caused to decrease in speed as the frequency decreases until the pendulum, P, breaks contact with C_2.

On the other hand if M_2 falls below the speed of the standard, the pendulum, P, will swing to the right making contact with C_1. This operation will close the circuit between the direct-current supply and the governor control motor. But this time the current flows through the switch (b) and into the field which causes the motor to run backward opening the governor, thereby increasing the speed of the generator and in turn produces an increase in frequency. This increase in frequency will cause the synchronous clock motor M_2 to increase in speed until it breaks contact between the pendulum P and C_1.

C_1 and C_2 are insulated from each other and the space between them is adjustable. The magnitude of this space depends on the time lag desired for the motors to cause the pendulum to regain the vertical position.

The universal is made of four bevel gears mounted within a frame of aluminum. The two gears in the horizontal plane are securely fastened to the shafts of the synchronous motors in order that they will rotate with the shafts of the motor. The two gears in the vertical plane are in mesh with the other two gears and are free to turn on a shaft made by extending the pendulum through the aluminum frame. These gears were obtained froma typewriter and considerable amount of friction may be noticed in their operation. To compensate for this loss in motion the gap between C_1 and C_2 can be decreased.

During some tests with the instrument the time that it

took the pendulum to move from one contact to the other was noticed in order to adjust the space between C_1 and C_2 for the shortest period possible to insure accurate operation. At the first trial the time of the period was forty-five seconds with approximately 7/16 of an inch between the two copper strips. After several adjustments the time was cut to fifteen seconds and the space measured 1/4 of an inch at this adjustment. There was a difference of 0.6 of a cycle in the frequences of the two supplies during these observations.

The first difficulty encountered was that of hunting in the speed of the generator caused by the time lag of the pendulum in going from one extreme to the other.

Fig.6 shows a means of decreasing the excess hunting in the frequency. This diagram is an enlargement of a portion of Fig.5 .

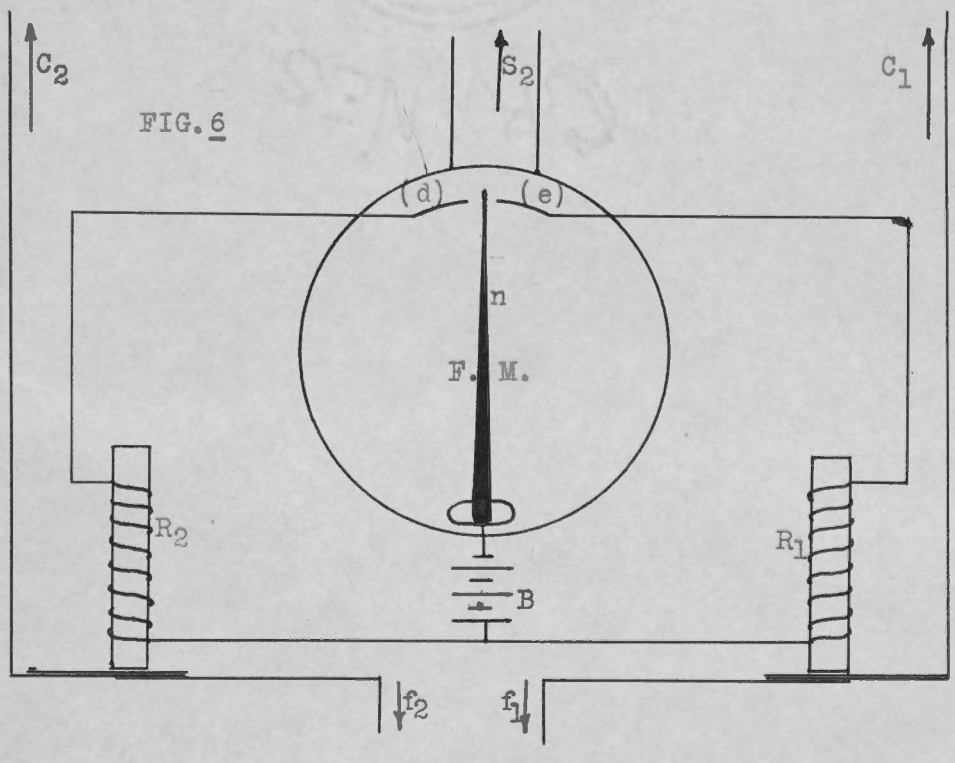


FIG. 6

F.M. is a standard Westinghouse switchboard type frequency meter. On the face of this meter is placed two thin metal strips (d) and (e). Strip (d) is so placed that the end nearest the pointer is on the graduated scale at fifty-nine and five-tenths cycles. Likewise strip (e) is so placed that the end nearest the pointer is on the graduated scale at sixty and five-tenths cycles. This will give a maximum variation of one cycle or plus or minus five-tenths from the standard sixty cycles. To the pointer or needle (n) is connected a source of small supply preferably a battery, B, which furnishes current for the two relays R_1 and R_2. The other connection from R_2 is to the small strip (d) on the face of the frequency meter. Likewise, the other side of the circuit from R_1 is connected to the strip (e). R_1 and R_2 are simple relays working on the principle of electric-magnetism. (a) and (b) are small strips of metal which when raised will open the circuit to either side of the direct-current motor and which when released from the magnet will fall again and close the circuit.

The frequency meter, F.M., is connected to the University power supply and when motor M_2 becomes slow the contact will be made between pendulum, P, and C_1 which operates the direct-current motor to open the governors. If the increase in frequency goes to sixty and five-tenths or above the needle (n) will contact with strip (e) and energize the relay R_1. When energized the relay R_1 raises the metal switch (b) and cuts off the motor in its operation of opening the governor. This

will prevent the governor from being opened too wide and also keeps the frequency from increasing to such a great amount that will cause the excess hunting in the frequency. On the other h hand when the University supply falls below the standard frequency of sixty cycles the pendulum,P, will make contact C_2 and start closing the governor as described above. If the closing of the governors causes the frequency to fall to fifty-nine and five-tenths or below the frequency meter pointer (n) will make contact with strip (d) causing relay R_2 to be energized. This in turn will raise the metal switch (a) and open the circuit cutting off the direct-current motor. This operation will prevent the frequency from falling too low which decreases the time lag between extremes and helps prevent hunting.

In either case when th needle (n) goes back to a position between the two contacts on the frequency meter the relays will be demagnetized and the metal contact switch (a) or(b) have sufficient weight to cause them to return to the original position and make the circuit complete when the pendulum makes contact again.

Trouble arose concerning the possibility of the supply of one of the synchronous motors being interrupted. In that case the other motor would continue operating and would tend to rotate the pendulum.

Fig.7 shows an answer to this situation. In each supply line is placed a relay switch similar to the relays R_1 and R_2 except that the relay in the University system,X_2, is energized by the current in the standard supply and the relay,X_1,in the standard supply line is energized from the University supply.

If the standard supply should be interrupted the synchronous motor, M_1, would stop and likewise the relay, X_2, would be demagnetized and the metal switch would be released opening the circuit of the University system. The same proseedure will occur in case the University power service should be interrupted.

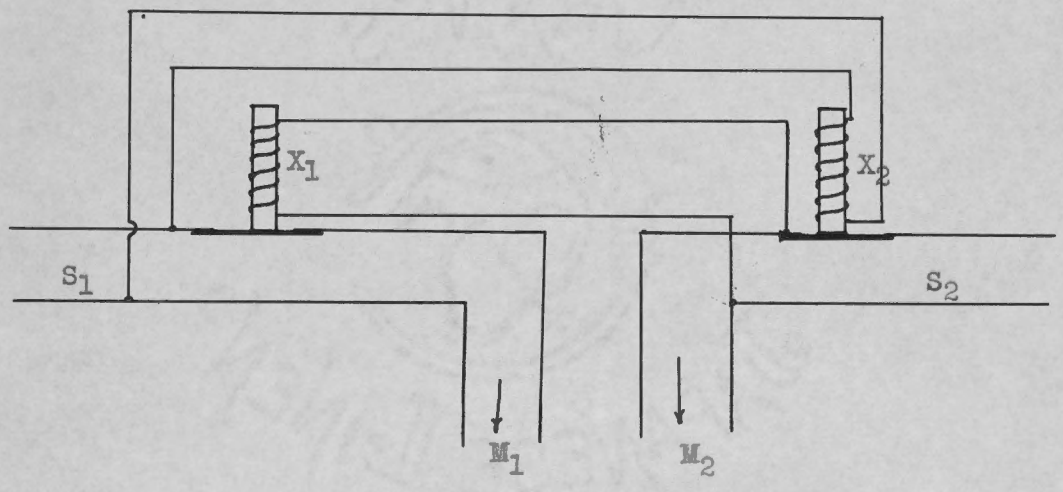


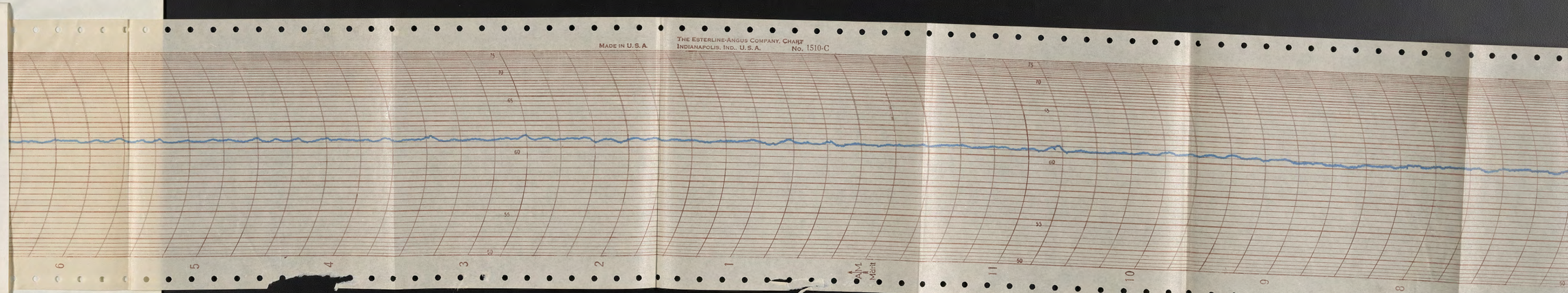
Fig.7

CONCLUSIONS

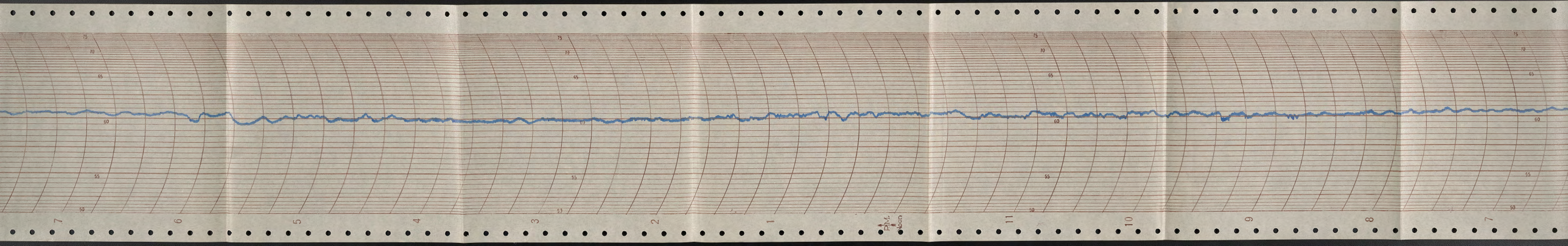
Although the automatic control device was not actually operated on the University power system, it did reveal its practicability in the tests carried on the laboratory.

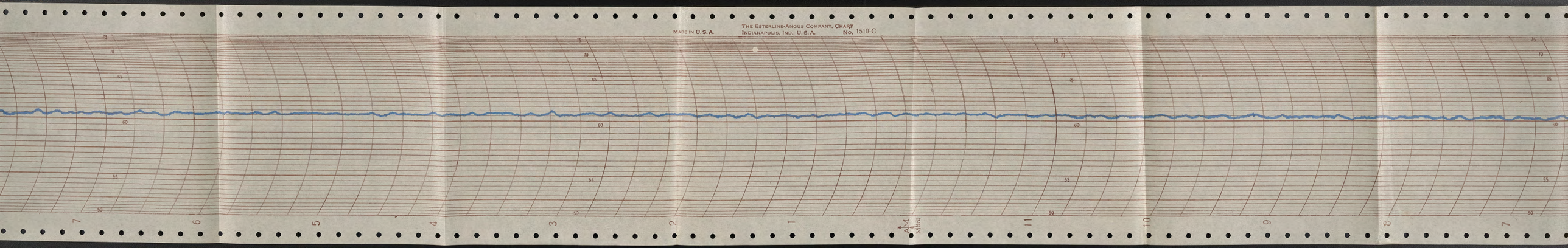
To test the apparatus the power plant supply was used as the standard and a Westinghouse motor-generator set used as the supply to be standardized. Instead of the double field reversible motor two banks of lamps was used. This plan of operations was used as the basis of the observations.

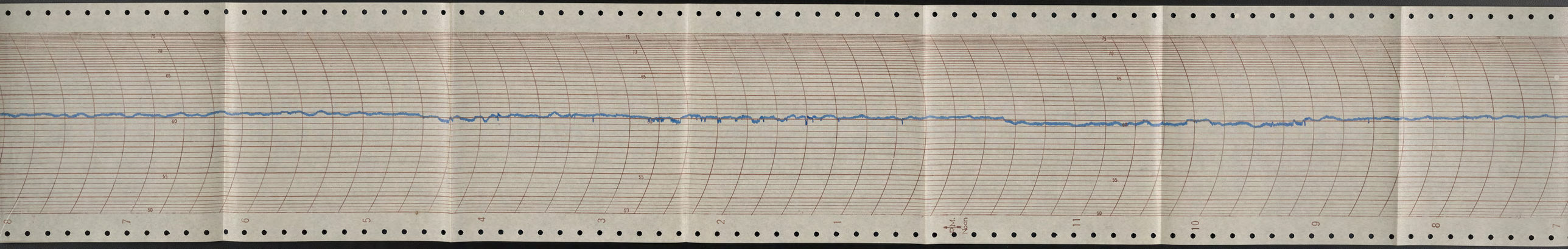
The project if developed would not only be applicable to those plants which already have standardized frequency systems on the switchboard, but could be used in all systems by using an accurate pendulum type clock instead of the synchronous motor on the standard supply.



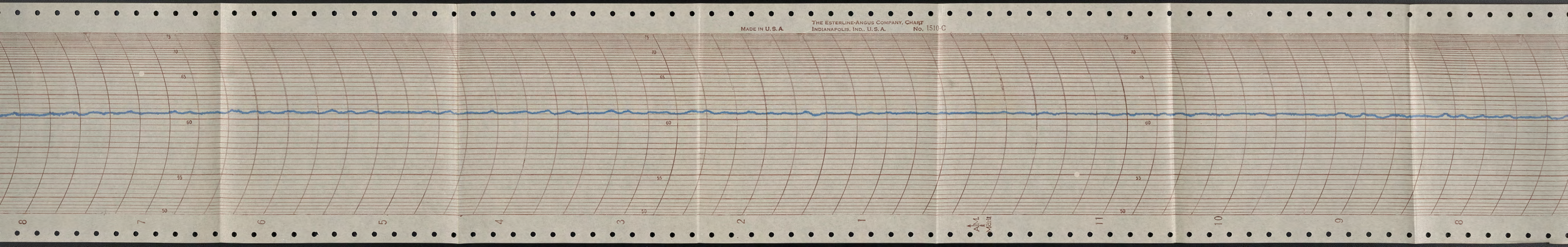
Graphic frequency for four days

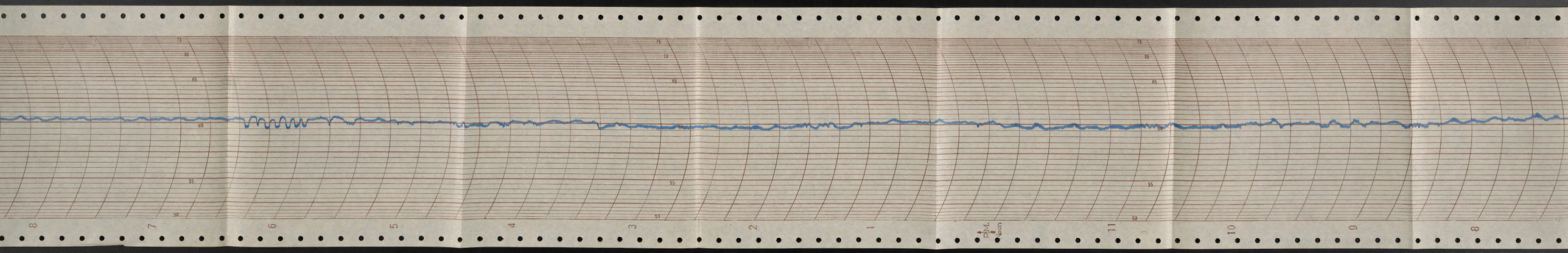

75
70
65
60
55
50
7
6
5
4
3
2
1
Noon
11
10
9
8
7

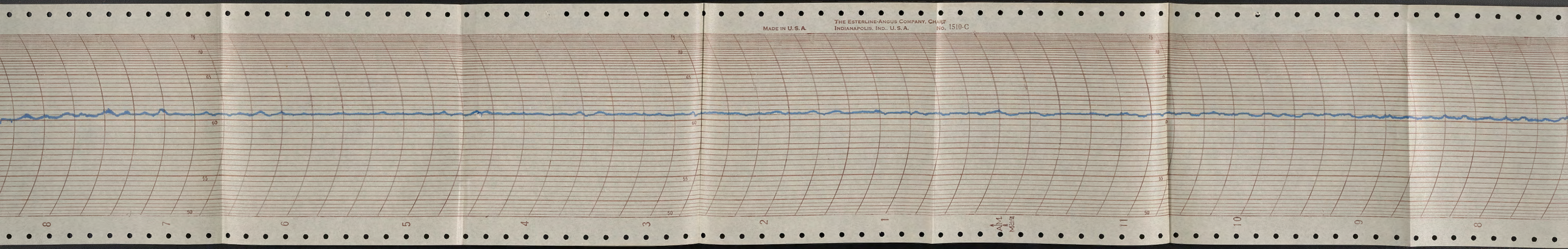

MADE IN U.S.A.
THE ESTERLINE-ANGUS COMPANY, CHART
INDIANAPOLIS, IND., U.S.A. No. 1510-C
75
70
65
60
55
50
7
6
5
4
3
2
1
11
10
9
8
7

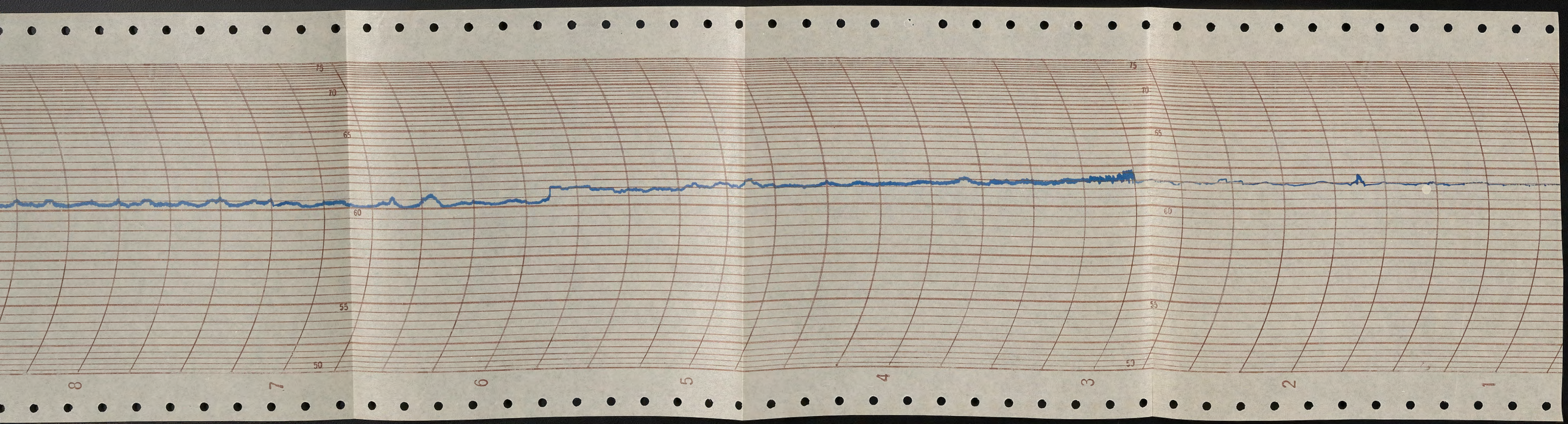

75
70
65
60
55
50
8
7
6
5
4
3
2
1
Right
Zoom
11
10
9
8
7

MADE IN U.S.A. THE ESTERLINE-ANGUS COMPANY, CHART INDIANAPOLIS, IND., U.S.A. No. 1510-C




75
70
65
60
55
50
8
7
6
5
4
3
2
1
Phil.
Com
11
10
9
8


MADE IN U.S.A.
THE ESTERLINE-ANGUS COMPANY, CHART
INDIANAPOLIS, IND., U.S.A.
No. 1510-C
75
70
65
60
55
50
8
7
6
5
4
3
2
1
11
10
9
8
AM
Mean


75
70
65
60
55
50
8
7
6
5
4
3
2
1

BIBLIOGRAPHY

1."Electric Clock Motors",in American Machinist,April 7,'32

2."Impulse Versus Synchronous Time Service,in Electrician, Volume 105, December 26,'30

3.Warren,H.E.,"Synchronous Electric Time Service",in Electrical Engineering,April,1932

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name J. G. Tarboux

Title Professor Electrical Engineering