NATIONAL BUREAU OF STANDARDS REPORT

6326

Progress Report

on

EVALUATION OF DENTAL CUTTING PROCEDURE:
METHOD AND APPARATUS

by

Robert R. Perkins
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NBS PROJECT		NBS REPORT
0708-20-3824	December 31, 1958	6326

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EVALUATION OF DENTAL CUTTING PROCEDURE: METHOD AND APPARATUS

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This work is a part of the dental research program conducted at the National Bureau of Standards in cooperation with the Council on Dental Research of the American Dental Association, the Army Dental Corps, the Dental Sciences Division of the School of Aviation Medicine, USAF, the Navy Dental Corps, and the Veterans Administration.

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EVALUATION OF DENTAL CUTTING PROCEDURE: METHOD AND APPARATUS

Abstract

There is a need for more information about the fundamental physical principles involved in dental cutting procedures. One portion of this need in regard to the selection or improvement of handpieces and rotary instruments can be satisfied by measurement of the power transmission from handpiece to instrument to tooth. Equipment and a method suitable for initiating such a study are described.

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1. INTRODUCTION

This report is the first in a series on the evaluation of rotary cutting devices in terms of their fundamental physical operating characteristics.

The clinical use of an instrument depends upon certain intangible factors other than physical measurement. However, more precise and fundamental measurements of performance would be of value to both dentist and dental manufacturer. All dental handpieces and rotary cutting instruments represent a means of transferring energy from a source of power to the surface of a tooth. It is the specific purpose of this paper to outline a method by which the physical entities associated with this energy transfer may be measured and to

describe in detail apparatus which has been developed in conjunction with this method.

2. METHOD

The formation of any new surface area, as in the chip formation associated with dental cutting, requires a certain amount of energy characteristic of the material cut. However, in the process of transferring this necessary energy to the tooth, by means of a handpiece, certain losses occur. Some of these serve only to raise the total energy consumed and may be neglected. Others, however, which result in the dissipation of portions of the energy in such undesirable forms as heat, noise and vibration, are of prime importance. Losses occurring in the tooth itself and in the instrument, which is in contact with the tooth, fall into this latter category.

The method proposed here consists of measuring the total energy transferred to the instrument by the handpiece and the proportions of this energy which produce useful cutting. The ratio of the useful work produced to the total energy consumed is the efficiency of the process and will vary (as will the rate of energy consumption) with such factors as instrument design, instrument speed, and applied load.

One means of determining useful work is in terms of the weight of material removed. The energy transferred from the handpiece to the instrument can be measured in terms of speed and torque.

These two factors are related in a way which is characteristic of the handpiece and power source and normally will not vary with changes in instrument or applied load. It is, therefore, possible to measure speed and torque (and thus power) under laboratory conditions and then subsequently to determine the energy transferred under other conditions by merely measuring speed.

In practice this has been done, for example, by measuring the torque delivered to the instrument shaft by an air turbine at various speeds while holding the air pressure constant. From the resultant data the torque-speed and power-speed curves may be plotted.* Using this handpiece at the same air pressure for laboratory or clinical cutting, the power transferred to the instrument may be determined by measuring the speed and consulting the previously determined curves.

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* The general expression for the power of a rotating device is

$$P = 2 \pi k n T$$

where
P is the power
n is the speed of rotation
T is the torque
k is a constant dependent upon the units used

If speed is measured in rpm and torque in gram-centimeters then P in watts is given by

$$P = 1.026 \times 10^{-5} n T$$

Because of the wide range in the speeds and torques developed by the various types of handpieces currently available, it was found desirable to construct separate test apparatus for low speed-high torque handpieces (such as the conventional belt driven type up to 50,000 rpm) and for the high speed-low torque handpieces (turbines, up to 400,000 rpm and torques up to 8 g-cm). In each case the apparatus included a means for loading the handpiece, and for determining the torque and speed simultaneously.

3. APPARATUS

3.1 Low Speed-High Torque Apparatus

An overall view of the low speed-high torque apparatus is shown in Figure 1. Basically, it consisted of (1) a pivot-mounted electromagnetic brake, (2) an optical system for viewing deflections of that brake and (3) a photoelectric system for measuring speed.

To measure torque, an aluminum disk 2 inches in diamater and 0.020 inch in thickness, was mounted on a mandrel, dynamically balanced, and placed in the handpiece to be tested. The principle of operation was based on the induction of eddy currents in the disk by its rotation between the poles of the electromagnet. These currents in turn interacted with the field produced by the electromagnet. This interaction retarded

the motion of the disk and produced a deflection of the pivot-mounted electromagnet. The magnitude of the deflection was a function of the braking torque applied to the disk.

Details of the pivot-mounted electromagnetic brake are shown in Figure 2. The square core was made from cold-rolled steel. Its outside dimension was 6 inches on each side and its cross-sectional area was 1/4 square inch. The length of the magnetic path was thus 22 inches. The air gap was 3/32 inch. The coils consisted of a total of 400 turns of 16 gauge enamel covered magnet wire. The magnet was energized by current from a 6 volt lead storage battery. The circuit was completed through platinum electrodes which extended below the brake into two mercury baths. This was intended to keep the friction on the brake as low as possible during deflectiom movements. A one ohm rheostat and a fifty ohm rheostat (the controls for which may be seen at the extreme left in the row of switches in Figure 1) were series connected in the circuit. This enabled vernier control of the magnetizing current from 0.1 to 10 amperes. Additional provision was made (by means of a double pole double throw switch) for reversing the direction of current flow in the magnet during successive runs, in order to compensate for residual magnetic fields within the core.

The axle of the brake was made from an aluminum rod, 5/16 inch in diameter and 6 1/4 inches in length. It was tapped on

either end and 1/4 inch hardened steel plugs were inserted to provide a bearing surface. Conical indents (150°) were drilled in the steel plugs to the axis and the entire assembly was supported on hardened steel 80° conical points secured by mounts at either end.

A two pound lead weight was suspended approximately four inches below the center of the axis and was partially immersed in a bath of liquid petroletum. This provided damping of the deflection movements.

A plane first surface mirror was mounted above the axle and oriented so as to reflect through a slit the image of a scale gradulated in millimeters which was housed in an illuminated box above. Through a series of mirrors deflections of the electromagnetic brake could thus be read through a viewing device, the ocular and tube of which may be seen at the right side of the cabinet in Figure 1.

Calibration was accomplished by suspending gram weights on the pivot-mounted electromagnetic brake and recording the readings as seen through the viewing device. These weights were placed 2 3/4 inches from the rotational axis of the brake. The assumption was made that the effective action of the brake upon the disk could be considered as occurring at the geometric center of the pole face. Since, under operating conditions, the disk was placed in the air gap at a point where the center of the pole

face was 3/4 inch from the rotational axis of the disk, a conversion factor of 3.67 was applied to the previously obtained values to convert the measured torque applied to the brake to that exerted on the handpiece.

The aluminum disk used for determining torque was also used for measuring speed. Figure 3 shows the disk as it appears to the photoelectric speed determining component of the apparatus. As can be seen, one half of the disk was darkened by painting it with a flat black laquer. A 929 photocell and direct coupled amplifier are contained within the 4" x 4" x 5" utility box shown at the left in the figure. The circuit diagram of the amplifier is given in Figure 4.

The light source is a battery operated 6 volt 6 watt incandescent lamp. The light was concentrated on the disk by means of a parabolic reflector. The aperature to the photocell was 1/4 inch in diameter and the distance from the disk to the cell was approximately 4 1/2 inches. With this arrangement variations on the order of from 7 to 9 volts were obtained at the amplifier output with each revolution of the disk. This alternating component was then fed to a HEATHKIT Model AF1 frequency meter, the scale of which was modified to read directly in revolutions per minute. A similar photoelectric system was employed to determine the speed of the dental engine used to drive the handpiece. The output of this system was fed to a second frequency meter. Both meters may be seen on the front panel in Figure 1.

3.2 High Speed-Low Torque Apparatus

A general view of the high speed-low torque apparatus which was used primarily for the study of turbine handpieces is shown in Figure 5. It consisted of (1) a torsion-wire electrodynamic brake, (2) a synchronous field exciter, and (3) an electronic system for speed determination. Small cylinders of CERAMAGNET* (barium ferrite ceramic permanent magnet material) were mounted on mandrels, dynamically balanced and placed in the handpiece to be tested. The dimensions of these cylinders varied -- the maximum size being 0.265 inch in diameter and 3/8 inch in length. (The reasons for varying their size will be considered in the Discussion.) Each cylinder was magnetized at a right angle to its long axis. This was accomplished by placing it in a gaussing apparatus which will be described under 3.3.

The principle of operation was based upon the interaction between the magnetic field produced by the permanently magnetized cylinder running in the handpiece and the oscillating magnetic field produced in the electrodynamic brake by the synchronous field exciter. This interaction resulted in a retardation of the motion of the cylinder and a deflection of the electrodynamic brake with consequent twisting of its suspension wire. The magnitude of this deflection, as read by a pointer on a scale,

* CERAMAGNET is the registered trademark of the Stackpole Carbon Company, St. Mary's, Pa.

was a function of the braking torque applied to the cylinder.

In effect the permanent magnet cylinder and the electrodynamic brake constituted a variable frequency synchronous motor which was used to oppose the driving force of the handpiece and thus permit the measurement of the torque produced as a function of speed.

Details of the brake are shown in Figure 6. Its core was made up of laminated silicon steel. The laminations were "E"-shaped and the completed assembly was 4 1/2 inches square overall. The cross-sectional area of the magnetic path was 1 1/4 square inches. The pole pieces were tapered on three sides and the pole face was made slightly concave along the vertical axis. The mean air gap was 0.270 inch. The two coils were parallel connected and wound to provide a nominal impedance of 3 ohms. Each coil consisted of ninety-four turns of 22 gauge double silk-covered magnet wire. Connection with the field exciter was made through platinum electrodes which projected into two concentrically arranged mercury baths beneath the assembly.

The upper and lower mounting yokes were made of aluminum. The lower yoke terminated in a stabilizing guide pin arrangement which limited lateral displacement of the assembly but which did not make physical contact when properly aligned. The entire assembly was supported by the upper yoke which terminated in a pin vise which grasped the suspension wire. The suspension wire was

0.020 inch piano steel, 5 1/2 inches in length. It was held in a second pin vise by the horizontal mounting bar seen at the top in Figure 6. The lower horizontal arm shown in the figure served as an additional stabilizing and alignment guide.

Calibration of the electrodynamic brake was accomplished by first calibrating a torsion bar assembly. This assembly consisted of two drawn nichrome wires (.030" x 10.0") which were held together at one end. Gram weights were then suspended at the free end of one of the wires while the angular deflection between them was measured. The tortion bar assembly was then moved to the electrodynamic brake. The bound end of the wires was centered at the vertical axis of the brake and securely held in place. Lateral forces were now applied to produce the same angular deflections between wires as previously obtained from the gram weights while the rotational movements of the brake were being read from the scale and pointer seen in the photographs. A table for converting scale readings to gram-centimeter torque values was then made.

The circuit of the synchronous field exciter is given in Figure 7. Basically it consisted of a nominally rated 80 watt power amplifier which was driven through an isolation stage by a variable frequency sine wave generator. The power amplifier used a pair of 807 output tubes operating class AB_2 into a 6400 ohm plate-to-plate load. A triode connected 6L6 was used as a

transformer coupled driver. A 6C5 isolation stage was employed to minimize loading effects on the generator and to flatten the output response curve. The frequency control circuit of the generator was a modified Wein bridge coupled to the power amplifier's output through a phase-sensitive network. This network employed a counter-feedback principle between the primary windings of the driver transformer and one side of the output transformer in order to provide a synchronizing voltage to the generator and thus assist in keeping its output "in-step" with the rotating cylinder. *

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* The construction of this field exciter is quite straightforward and may well be undertaken by anyone having general knowledge of good construction practice. The following notes are presented to assist in making the necessary adjustments after construction has been completed:

All controls are of the screwdriver type except R_1 which is the manual frequency control. R_2 should be set to the minimum value which will sustain oscillations when R_1 is set to within 90% of its full clockwise position (i.e., h.f. range). This adjustment should be made with only tubes V_1, V_2, V_7, V_{10} and V_{11} in their sockets. (This inactivates the feedback network.) All tubes except V_9 should then be inserted and a VTVM placed between the grid of V_4 and the bus ground. R_3 and R_4 are then "juggled" to obtain the nearest constant 15 volt reading which is possible while R_1 is being rotated throughout its full range. R_1 should then be set to midpoint. The VTVM should be moved to the rotor terminal on R_5 and this potentiometer adjusted to provide - 30 volts with respect to ground. A dummy resistive load of 3 ohms should then be placed across the secondary of the output transformer. V_9 may then be inserted, and after warmup, the adjustments on R_5 should be repeated. The field exciter is now ready for use and should produce good quality sine waves of near constant amplitude when observed on a scope across the dummy load. The range should be approximately 150 to 8000 c.p.s. as R_1 is moved throughout its full range.

In this apparatus as in the low speed-high torque apparatus a HEATHKIT Model AF1 frequency meter was used for speed measurement. It was supplied with signals from either of two points in the field exciter circuit through Switch S_1 (see Figure 7). To obtain "free speed", when the field exciter was not turned on, it was switched to the primary of the output transformer. In this position it measured the frequency of the e.m.f. generated by the magnetized cylinder rotating in the region of the electrodynamic brake. When the field exciter was activated, the meter was switched to the primary of the driver transformer where it measured the frequency of the synchronous e.m.f. being supplied to the electrodynamic brake. This switching was necessary because of the very high peak-to-peak voltages developed in the primary of the output transformer when the field exciter is on and because of the abundance of harmonics present as a result of the inductive loading effect of the electrodynamic brake.

3.3 Apparatus for Measuring Speed Under Clinical Conditions

Figure 8 shows the circuit diagram of an extremely stable high gain amplifier designed for use in conjunction with a frequency meter to measure speed under both laboratory and clinical conditions. The principle of operation is similar to that described by Richards [1]. Electromotive force induced in an electromagnetic pickup by cross magnetized instruments is greatly amplified and its frequency is read directly as revolutions per minute on a

HEATHKIT AF1 frequency meter. The electromagnetic pickup was simply a coil consisting of approximately 1000 turns of 32 guage enameled magnet wire wound about a 1/4" x 1/2" x 2" soft iron core. The coil was center tapped to match the balanced input of the amplifier. Balanced input was employed because of its common signal cancellation characteristic. The tube selection, the values of plate load resistors and the DC operated filaments were all design features incorporated to contribute to great gain, high stability and low noise characteristics. A separate chassis was used for the amplifier's power supply. This minimized shielding problems and simplified the heat dissipation problem associated with the voltage dropping resistors of the DC filament circuit.

Even with instruments which are rather difficult to cross-magnetize (e.g. No. 700 carbide burs), this apparatus gave reliable speed measurements when the pickup was placed within 4 inches of them. Thus it may be employed clinically by holding the pickup outside the mouth near the patient's cheek.

Figure 9 shows a photograph and the circuit diagram of an instrument which was found useful in conjunction with the other apparatus which has been described. It may be called a Gaussing-Degaussing Apparatus.

Ferromagnetic materials may be magnetized or demagnetized at will by placing them in appropriate magnetic fields. For

magnetizing, a strong unidirectional field is used while for demagnetizing a decaying oscillating field is used. On the apparatus shown either type of field may be produced by selecting the position of the SPDT switch.

When a magnetized instrument has been run in a handpiece for a period of time part of the magnetism will be transferred to its surroundings. This results in partial magnetization of some of the component parts of the handpiece. Such a handpiece will produce unreliable results when the speed of an instrument it is driving is being measured by this method. (The indicated speed will be some multiple or sub-multiple of the true speed.) Degaussing of the handpiece and the instrument followed by remagnetization of the instrument will restore the conditions required for accurate measurements.

The core of the apparatus, which may be seen on the right in the photograph, was made by interleaving the laminations of a discarded power transformer. The size of the air gap was controlled by means of the bar-knob which raised or lowered the upper half of the core. The two coils were series connected and each consisted of approximately 200 turns of 22 gauge magnet wire.

In the "Gauss" position of the switch, unfiltered direct current was applied to the coils through the half-wave selenium rectifiers. The pulsating nature of this current was very effective in magnetizing materials of relatively high incremental permeability (e.g. steel shafts). In the "degauss" position,

the alternating line current was applied to the coils through two series connected 250 ohm power rheostats. These rheostats permitted the controlled reduction of the oscillating magnetic field strength which accomplished the desired degaussing action. The neon bulb served as a visual indicator of the voltage across the coil.

4. DISCUSSION

The low speed-high torque apparatus has been found to be most useful in the study of conventional and ball-bearing type handpieces. An example of the type of data obtained with this apparatus is shown in Figure 10. While the potential torque measuring range of the low speed-high torque apparatus is very great it cannot be effectively employed at speeds much higher than 50,000 R.P.M. This is, of course, due to the large amount of power required to drive the two inch disk at the higher speeds. By appropriate mathematical treatment values for torque at speeds somewhat in excess of 50,000 R.P.M. may be calculated by extrapolation of data obtained from characteristics developed for a specific disk running at speeds of less than 50,000 R.P.M. This has its limitations however. Some improvement might be expected by modification of the design to accommodate smaller disks; but it should be pointed out that as the site of the eddy current action is moved closer to the rotational axis of the disk, the braking effect drops rapidly.

The high speed-low torque apparatus is highly effective at any speed up to 200,000 rpm when the maximum torque developed does not exceed 6 to 8 gram-centimeters and with reduced effectiveness to speeds approximating 400,000 rpm. It is, therefore, well suited to the study of air turbines. An example of the speed-torque curves obtained with this apparatus is shown in Figure 11.

Two problems have been encountered in the use of the high speed-low torque apparatus. The first is somewhat analagous to the disk problem in the low speed-high torque apparatus; i.e., it is difficult to fabricate cylinders which will run consistently at the top speeds which some air turbines are capable of developing. It was for this reason that cylinders of various sizes were tried. However, it has been rather conclusively demonstrated that the dynamic balance (or "trueness") of a cylinder is more of a factor in determining its ultimate speed than is its size per se.

In some instances it has been necessary to regrind the cylinders while they are being driven by the handpiece in order to achieve maximum rotational speed. This appears to reflect an imbalance in the turbine that is offset by introducing a compensating imbalance in the cylinder. In these cases the final cylinder may be considerably distorted in shape and will operate efficiently in only one position relative to the bur tube.

The second limitation has to do with the frequency response characteristics of the electrodynamic brake. The flux density in the air gap drops at frequencies above 4000 c.p.s. (which corresponds to 240,000 rpm). Much of this is due to core losses and might be obviated by the use of one of the newer Ferrites as a core material. Larger steel cores, more "sophisticated" coil windings and a higher powdered field exciter might also be expected to extend the useful range of this apparatus.

5. SUMMARY

The instruments developed are suitable for evaluation of dental handpieces and rotary cutting instruments from speeds of a few thousand for belt driven handpieces to 400 thousand revolutions per minute for some turbine types.

6. BIBLIOGRAPHY

1. Richards, J. R, and Nielsen, A. G. A Tachometer for the Evaluation of Rotary Cutting Speeds. J. D. Res. 37, 91 February 1958.

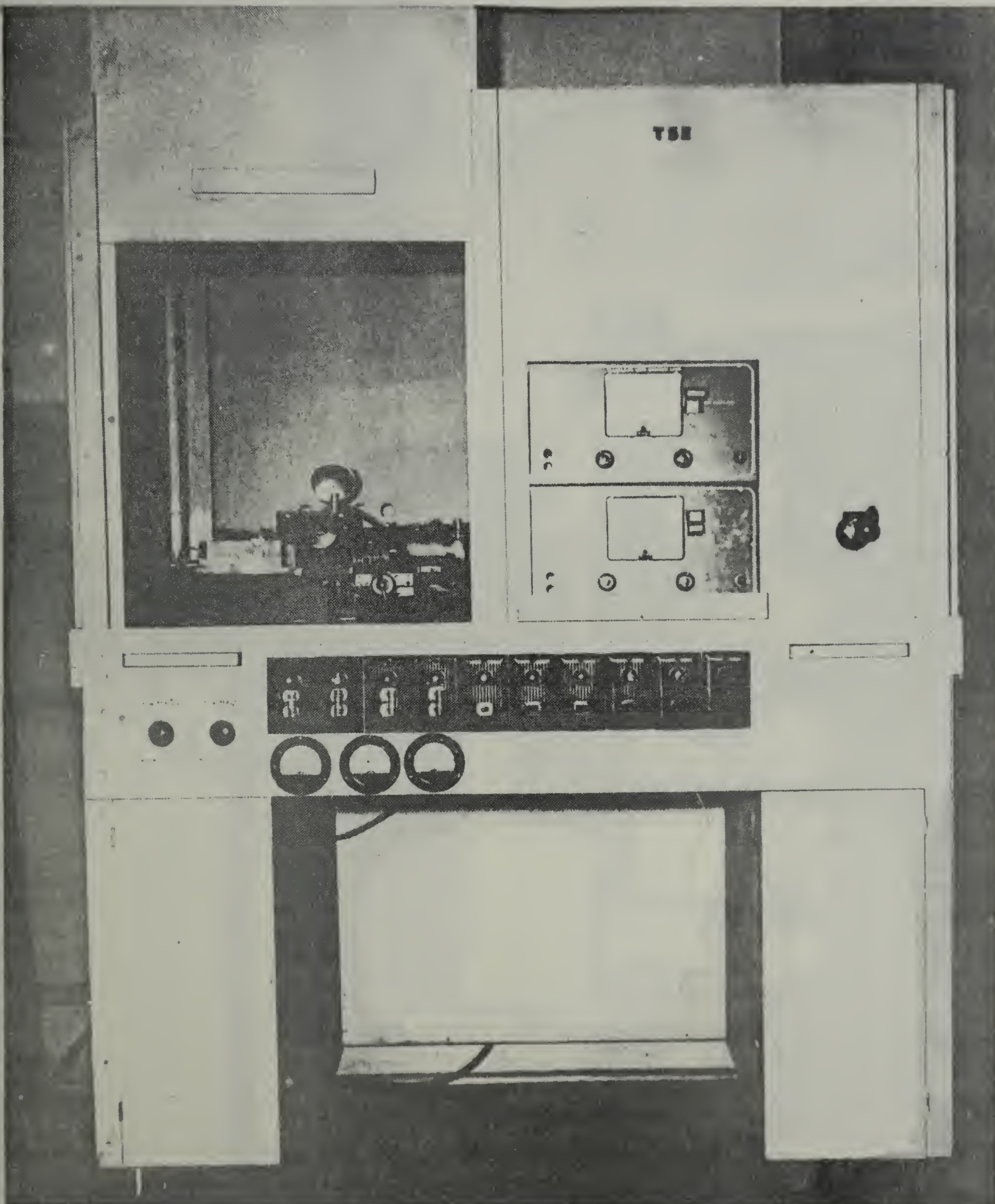

Figure 1. An overall view of the low speed-high torque measuring apparatus.

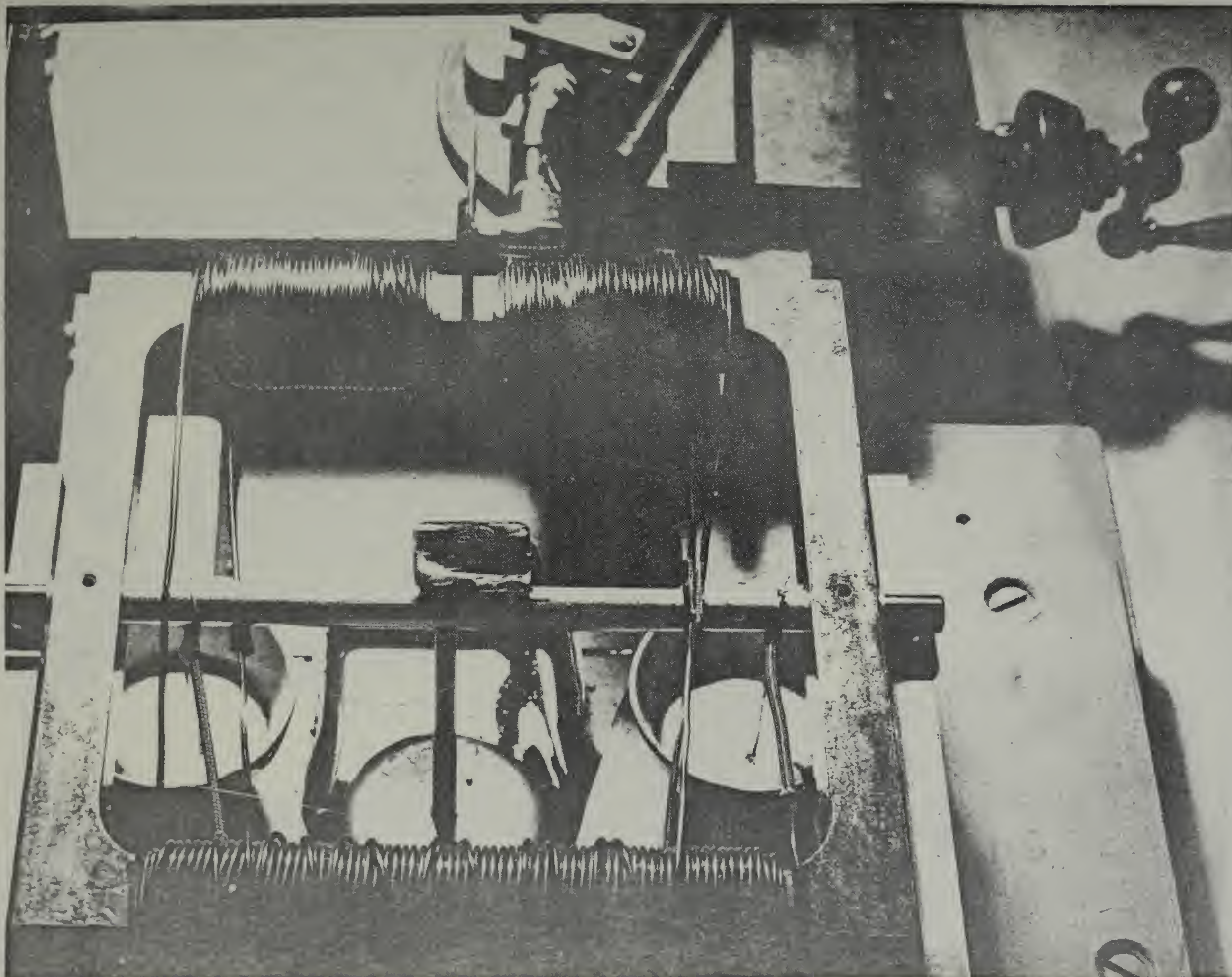

Figure 2. Closeup showing details of the electromagnetic brake.

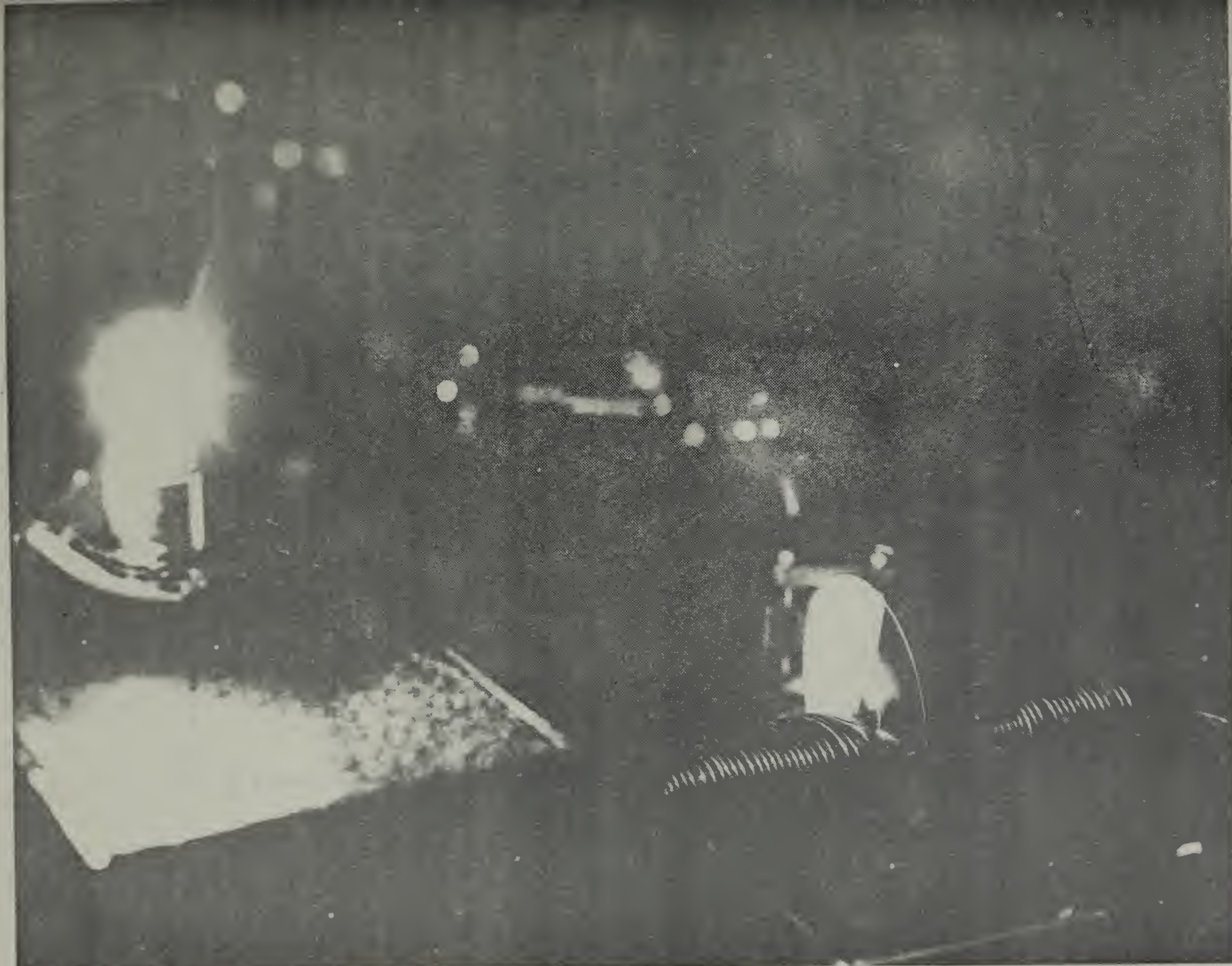

Figure 3. The sectored aluminum disc as seen by the photoelectric speed measuring apparatus.

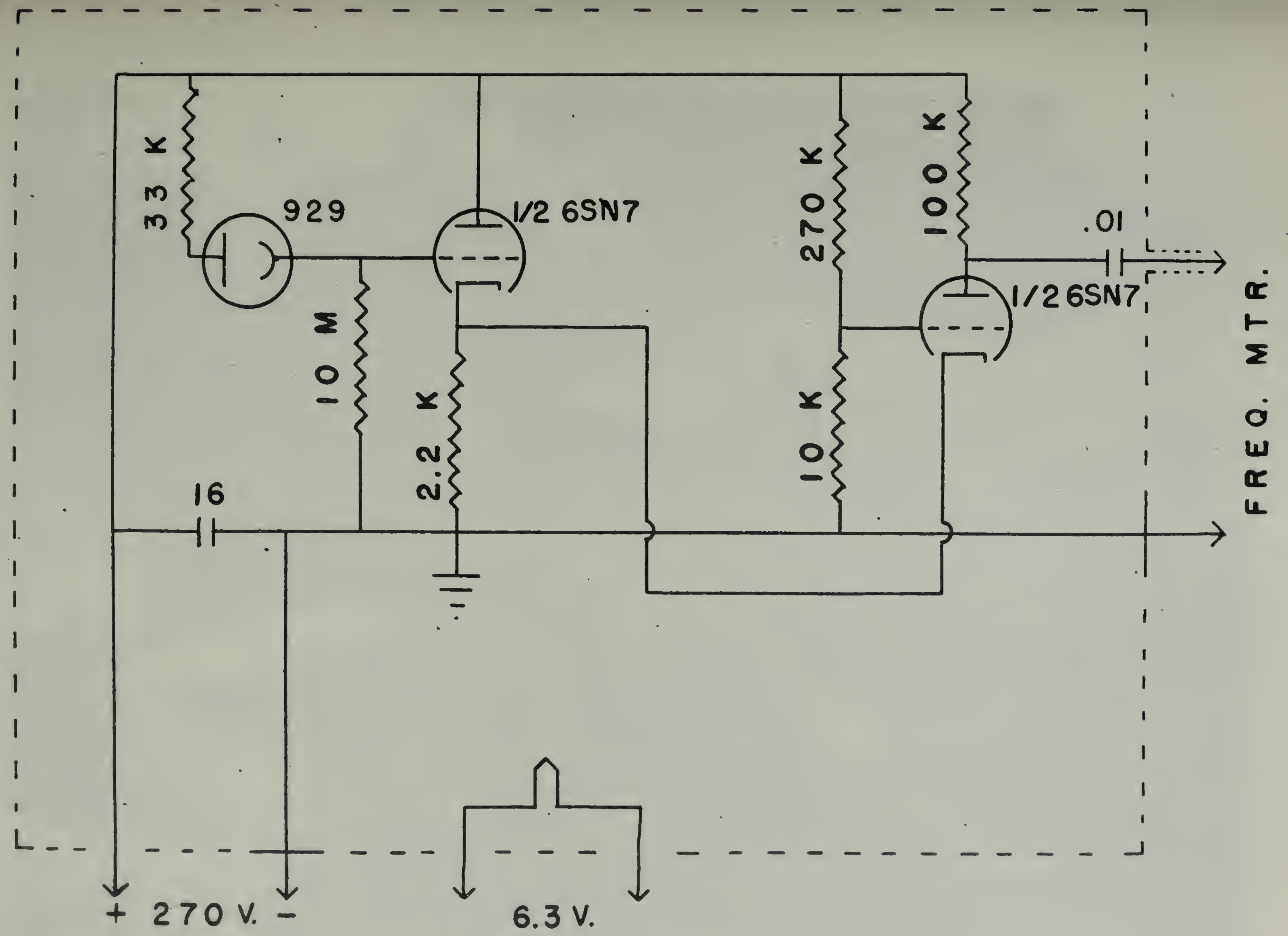

Figure 4. Schematic of the photoelectric amplifier employed.

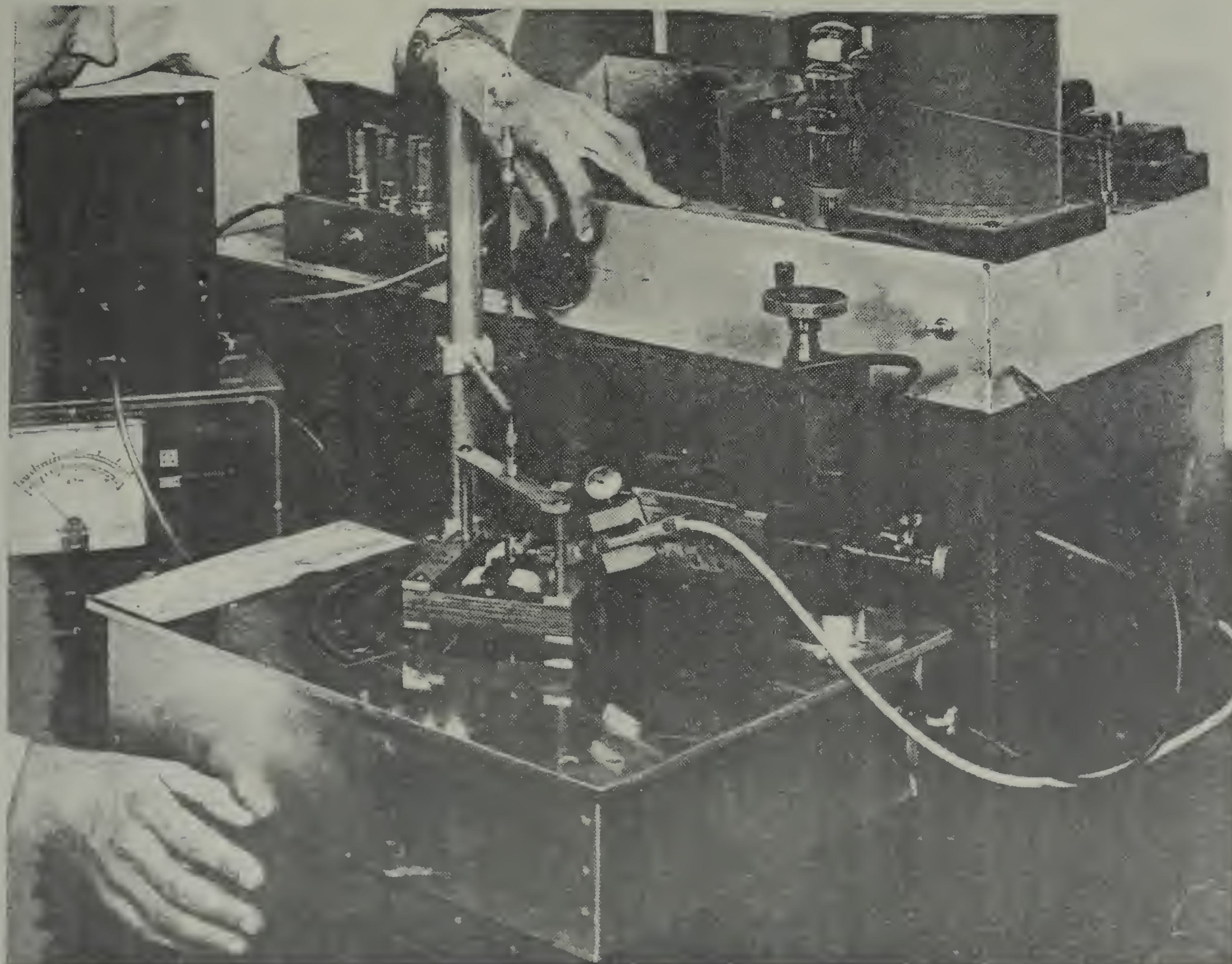

Figure 5. Apparatus employed for the high speed-low torque measurements.

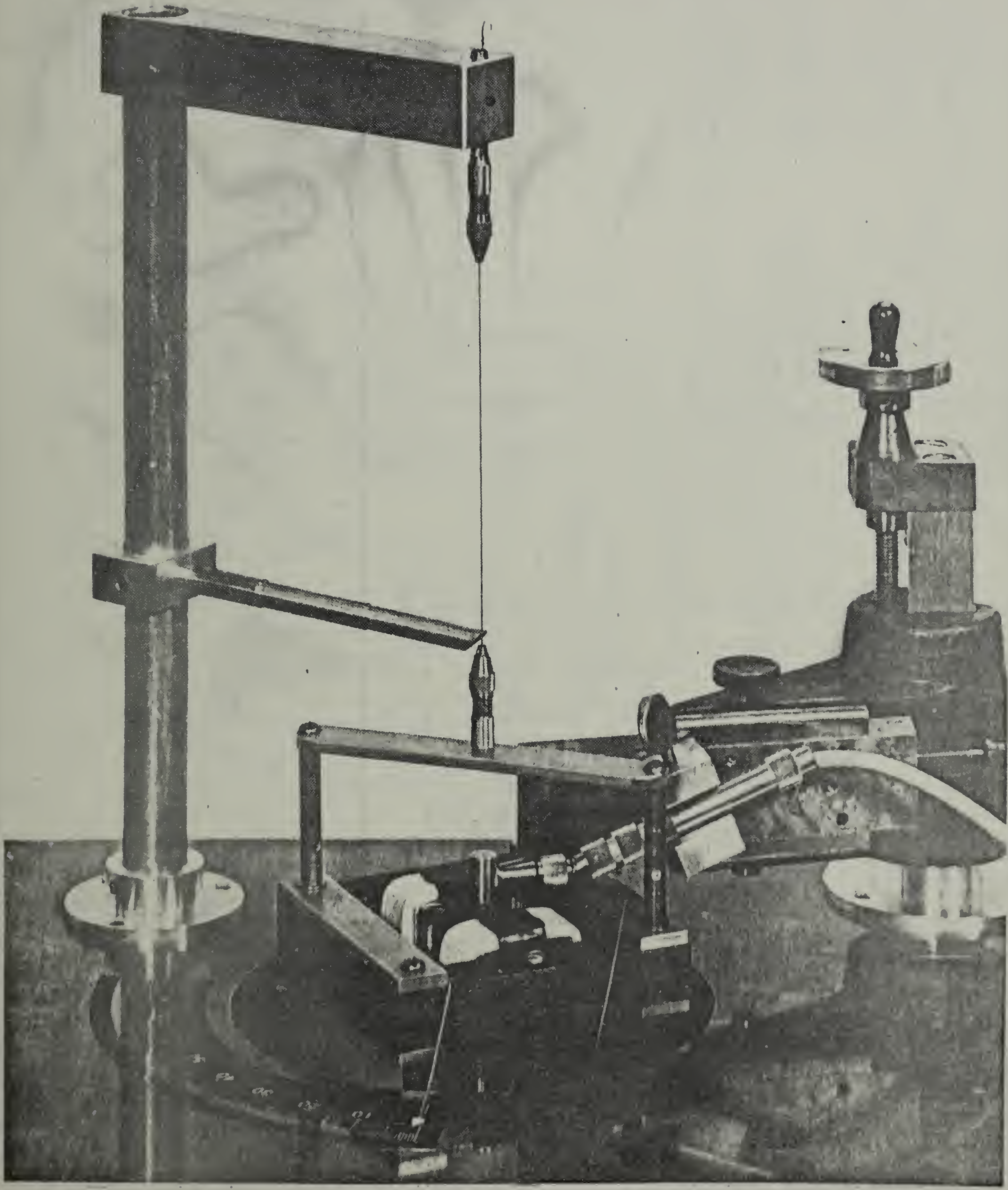

Figure 6. Closeup showing details of the electrodynamic brake.

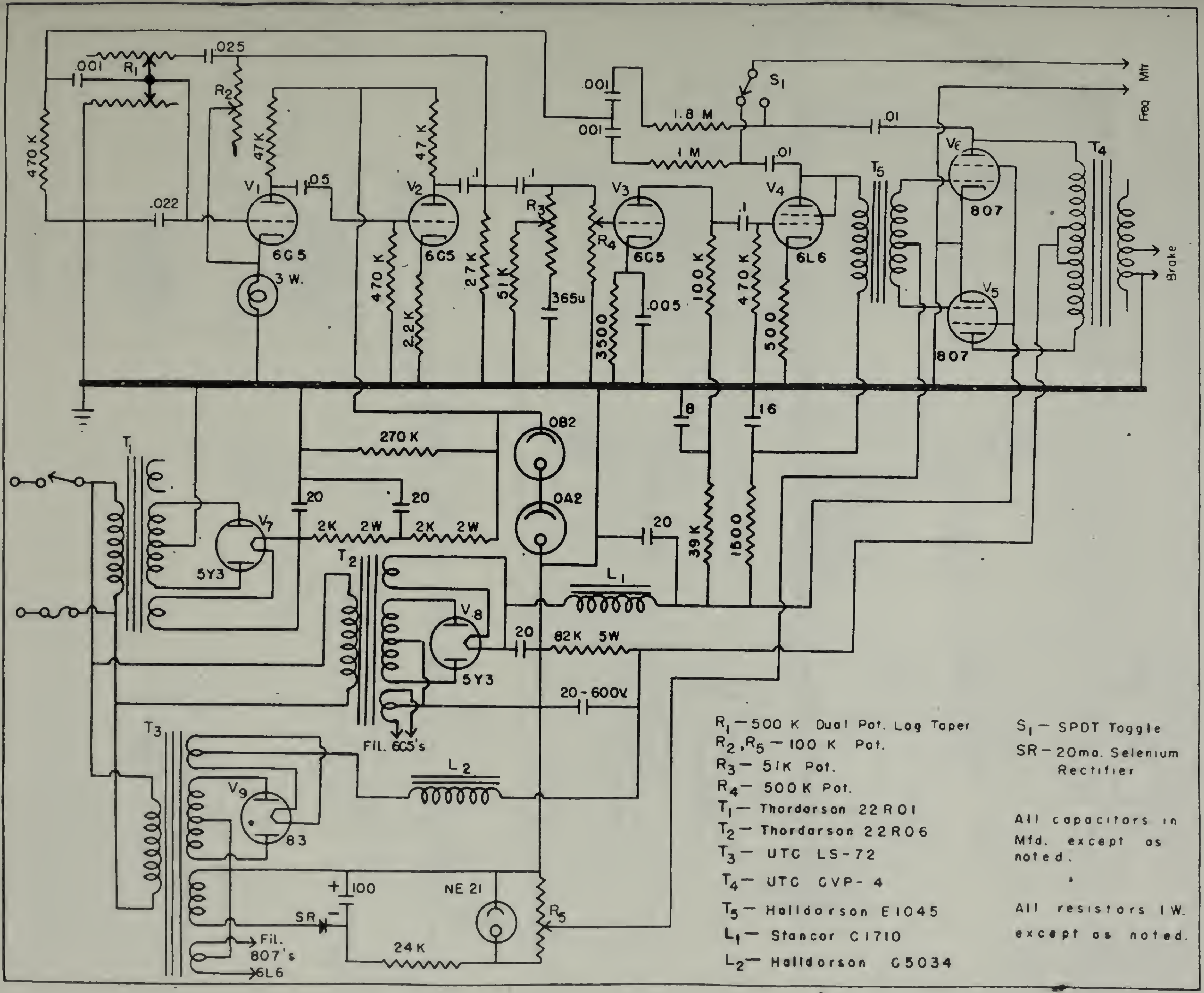

Figure 7. Schematic of the synchronous field exciter.

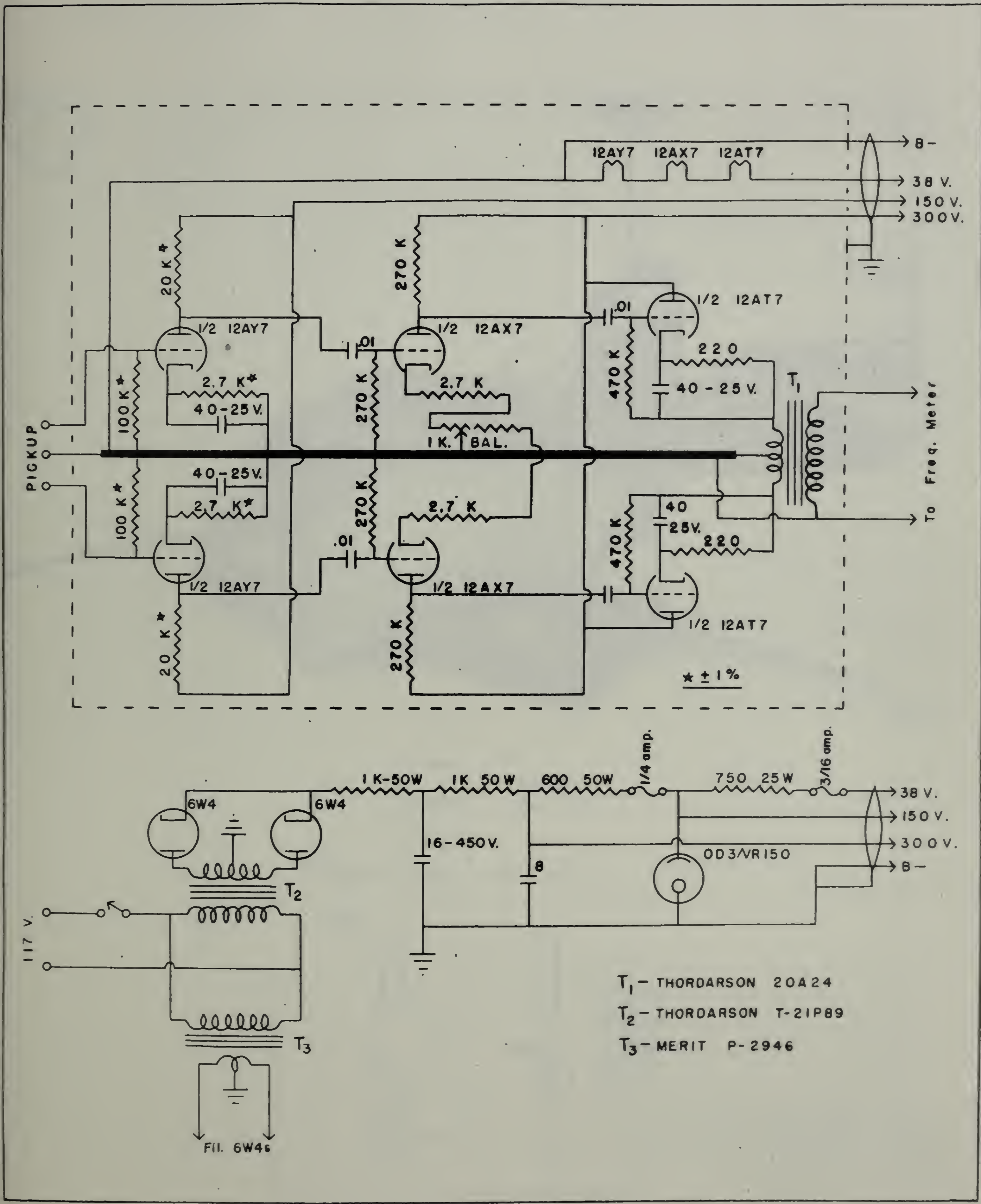

Figure 8. Schematic of the balanced-input high-gain amplifier employed in clinical and laboratory speed determinations.

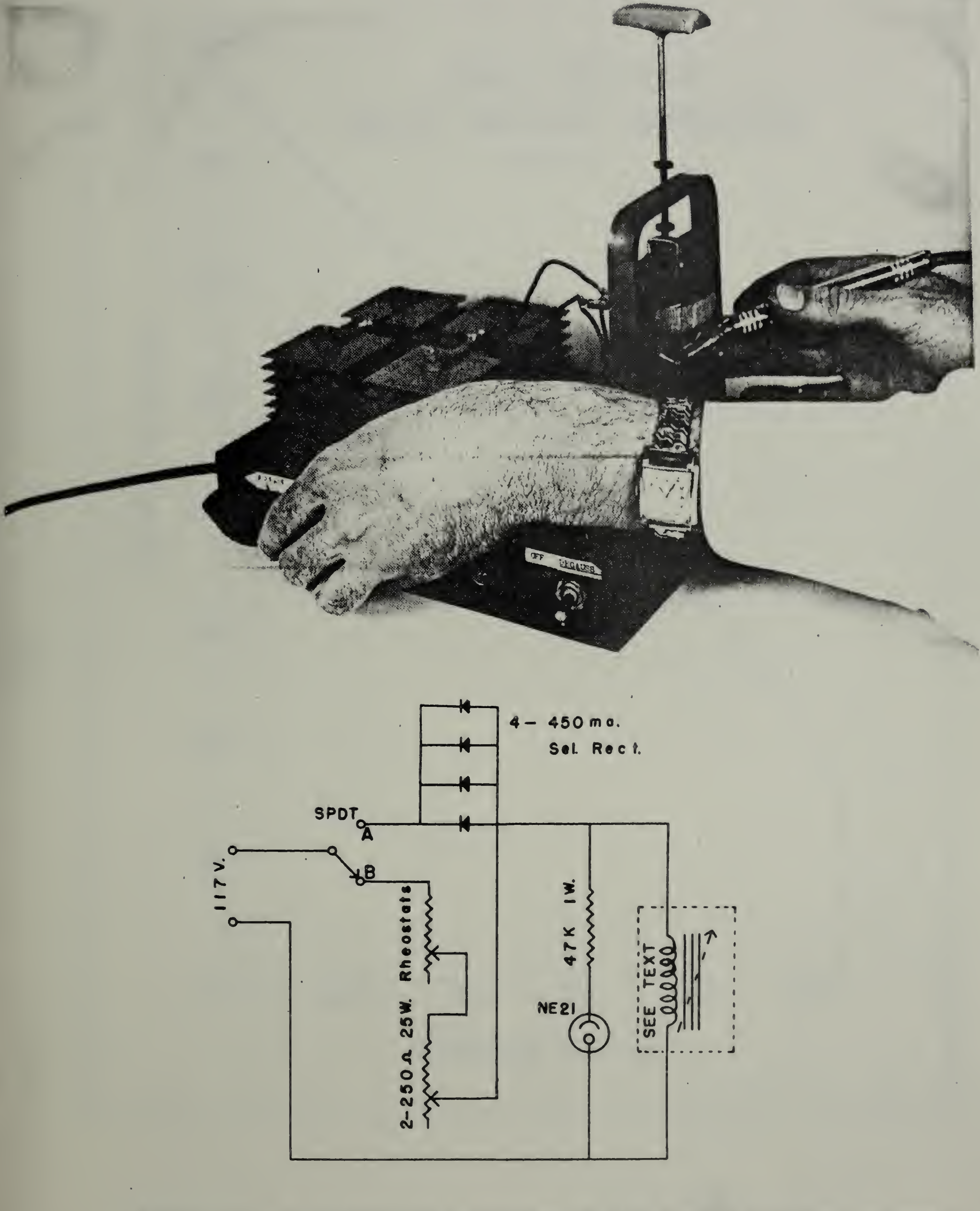

Figure 9. Photograph and circuit of the "Gauss-Degauss" apparatus.

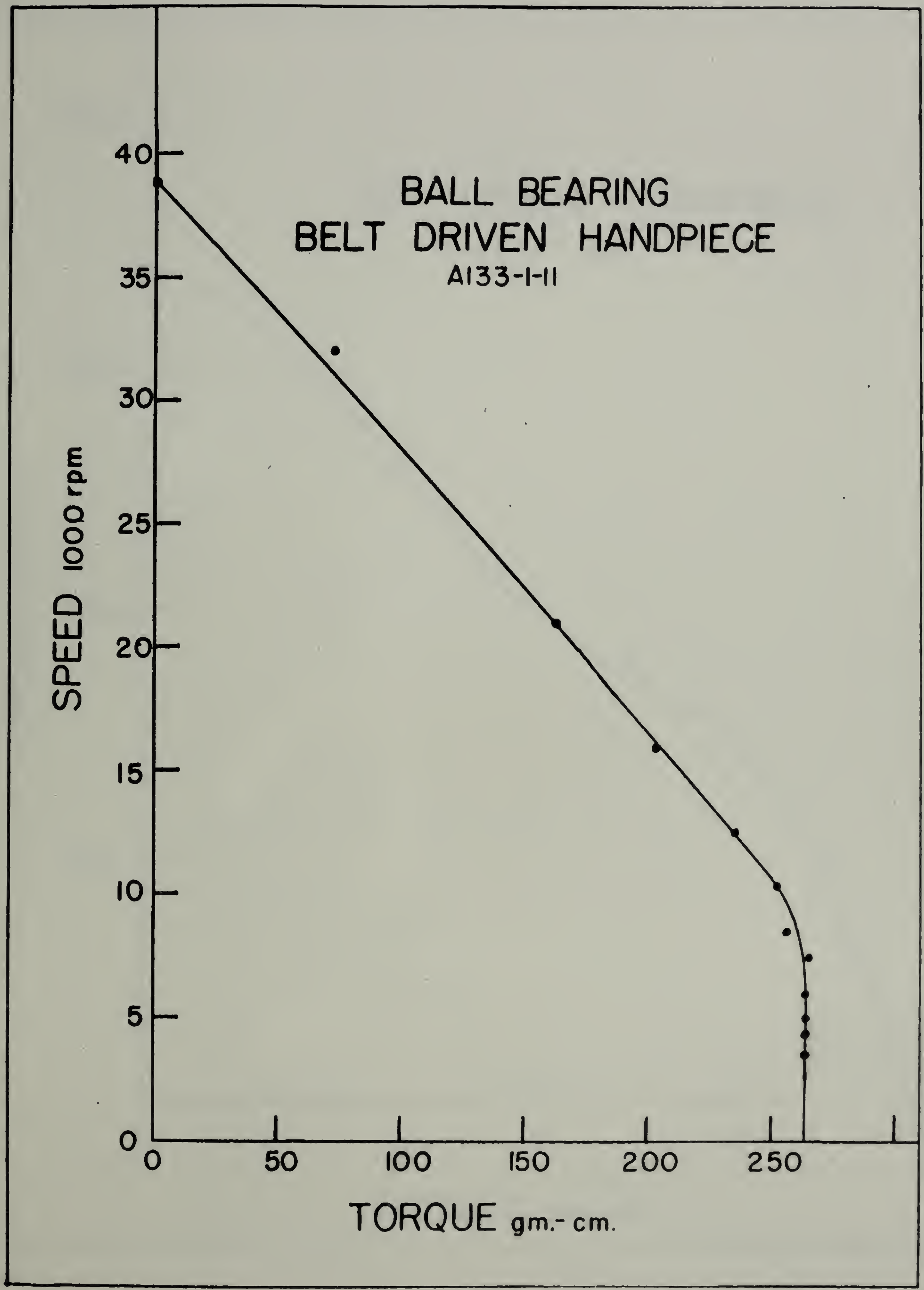

Figure 10. A speed-torque curve obtained with the low speed-high torque apparatus.

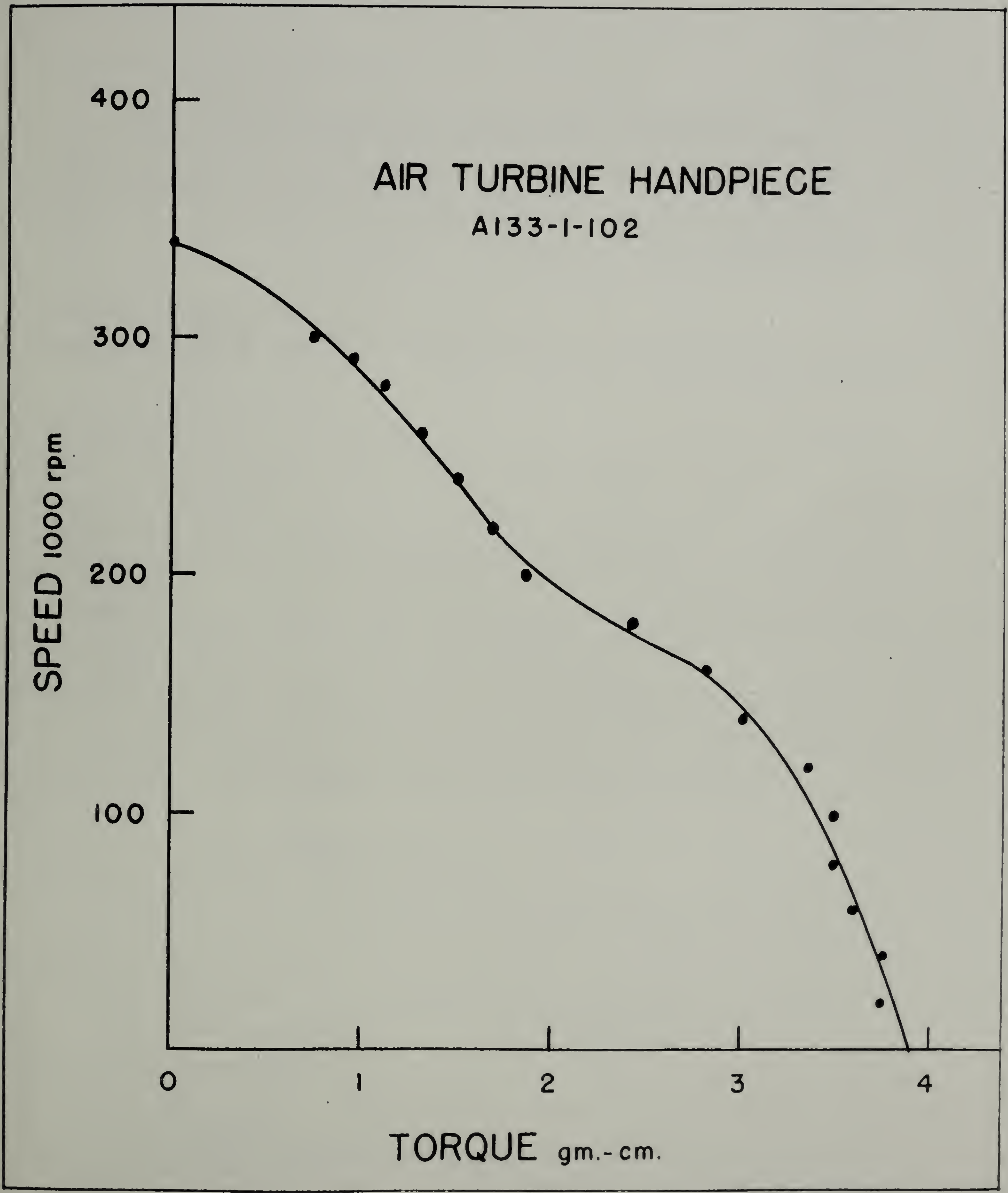

Figure 11. A speed-torque curve obtained with the high speed-low torque apparatus.

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