NATIONAL BUREAU OF STANDARDS REPORT

6433

Progress Report

on

MECHANICAL EVALUATION OF SOME

HIGH SPEED HANDPIECES

by

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MECHANICAL EVALUATION OF SOME HIGH SPEED HANDPIECES

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U. S. DEPARTMENT OF COMMERCE
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MECHANICAL EVALUATION OF SOME

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Abstract

The power transmission characteristics of a series of dental air turbine handpieces were studied. The torque produced as a function of speed was determined for each handpiece tested. The effects of air pressure, instrument size, and instrument balance upon the speed and power were investigated. Increased pressure was found to be more effective in increasing power than in increasing speed. The size of the instrument was found to have negligible effect upon the power output in comparison to the effect of dynamic balance.

I. INTRODUCTION

The introduction in the last few years of a wide variety of high-speed dental handpieces and instruments has emphasized the need for some method of evaluating dental cutting procedures. The dental literature has been filled with papers related to the use of high speeds, and a complete bibliography on the subject would run to several hundred items for the last five years alone. Only a very few of these papers, however, have been concerned with the mechanism of cutting or the instruments themselves [1-3]. The majority have been directed toward techniques for their clinical use.

The Dental Research Section of the National Bureau of Standards has for several years conducted a program of research into various non-clinical aspects of the dental cutting problem [4-9]. One portion of this program has been the investigation of the mechanical operating characteristics of dental handpieces. This paper presents our findings and conclusions in regard to one group of these handpieces, the air turbines.

The program as a whole is directed toward providing a more fundamental understanding of the cutting process with particular emphasis upon the energy considerations involved. A wide variety of handpieces was studied to

provide basic information in regard to the conditions that are encountered clinically. These handpieces included belt-driven designs having maximum speeds from 6,000 to 150,000 rpm, and water turbines, as well as the air turbines discussed here. It is hoped that this study not only will provide a basis for quantitative measurement of the characteristics of different types of handpieces but also will lead to a better understanding of the cutting process itself.

The method employed involves measurement of the energy transferred at several places within the cutting equipment, most particularly the energy transfer from the handpiece to the instrument and from the instrument to the surface being cut. This permits the comparison of the useful work obtained (cutting) to the losses (heat, noise and vibration) and allows an evaluation of the relative efficiency of various handpiece-instrument combinations. A detailed description of the equipment developed and methods employed in this study appears elsewhere [10], and only a short discussion will be given here.

II. EXPERIMENTAL PROCEDURE

The air turbines tested are listed in Table 1. As indicated there, the number of samples tested ranged from

one to four. The Midwest handpiece tested was an experimental design employing latch-type burs rather than the friction-grip design presently available. The other handpieces were all standard commercial models.

The operating characteristics of the handpieces were studied by determining the torque delivered to the instrument shaft by the handpiece at various speeds. An overall view of the equipment used for this purpose is shown in Figure 1, while a close-up view with a handpiece mounted for testing appears in Figure 2.

This apparatus was designed to produce a braking effect upon the handpiece by interaction between a synchronous magnetic field and a permanent magnet ferrite cylinder mounted in the handpiece. The braking field was brought into synchronization with the handpiece and the field strength increased until the handpiece speed was controlled by the field frequency. The handpiece speed was then varied by changing the frequency while the torque produced at various speeds was observed.

Calibration and reading errors cause a relative uncertainty of about five percent between the individual observations on a single run for both speed and torque. Absolute values of torque are known to the same accuracy

but drift in calibration of the frequency measuring system induces a maximum additional uncertainty of 5% in the absolute speed determinations.

Results and Discussion

A typical torque-speed relationship found by this technique is shown in Figure 3. The shape of this curve is typical of all of the turbines tested. It has been generally observed clinically that the torque produced by the air turbines is much smaller than that produced by conventional belt-driven handpieces. For example, the maximum torque produced in this run, about 10 gram-centimeters, is attained at minimum speed and may be compared with the 250-300 gram-centimeters maximum torques achieved by typical ball bearing belt-driven handpieces as shown in Figure 4.

The results obtained, particularly in some of the early runs, were not always as regular as those of Figure 3. Data of the type shown in Figure 5 were often obtained and in some cases the curves were as irregular as that shown in Figure 6. In this case, at the air pressure used, (30 psi), the handpiece would reach a maximum speed of only 110,000 rpm. When that speed was approached the handpiece became increasingly noisy and the cylinder ran

very eccentrically. Gradually increasing the air pressure made little difference in the speed until near 50 psi, when the speed suddenly increased to 400,000 rpm. Reducing the pressure to 30 psi produced a free running speed of 360,000 rpm. From that point the torque-speed curve could be traced to 300,000 rpm where the torque dropped toward zero. It was impossible to follow the curve continuously through this range and the middle section (between 300,000 and 100,000 rpm) was derived only by pressure cycling. When this was done, however, it was possible to follow this portion of the curve satisfactorily at 30 psi pressure.

This behavior was attributed to a resonance effect. The regular spacing of the speeds at which reduced torques appear, support this conclusion. Major drops occurred near 100,000 and 300,000 rpm and a smaller drop at 200,000 rpm. Although the magnet cylinders and the handpiece rotors were themselves well balanced, it was conceivable that, when the magnets were inserted in the handpiece, errors of alignment or centering might make the rotor-cylinder combination dynamically unbalanced. As a result, an attempt was made to grind the magnet cylinder into dynamic balance while driving them with the handpiece.

Figure 7 shows three of the magnet cylinders used. The one on the left has been ground and balanced relative to its shaft, while the others have subsequently been balanced in a handpiece. Of the three, the one on the right ran the fastest in spite of its rough appearance. Improvement, when it occurred, was often dramatic though not readily predictable. Table 2 shows the results of a series of successive grinding passes on three cylinders being balanced for the same handpiece.

The particular rotor with which these data were obtained was very sensitive to defects of balancing, although a previous rotor in the same handpiece had shown a much less marked effect.

Somewhat similar, though less extreme behavior was observed with burs. When several burs of the same size were tested, they were commonly observed to run at different maximum speeds. Also, reducing the pressure to the handpiece to levels of 5 to 10 psi at times produced results with burs which closely resembled those with unbalanced cylinders. In the case of the burs, however, increase of pressure back to the normal operating range or removing and repositioning the bur in the handpiece were sufficient to let the handpiece escape the low speed

resonance and achieve normal free-running speeds. Apparently the same type of effects occur with the cylinders and with burs. However, because of the relatively small mass of the burs the effect becomes apparent only under those circumstances where the torque of the handpiece is already marginal, near maximum speed or at very low pressures. Diamond instruments should be expected to produce similar results intermediate to these two cases.

Table 3 illustrates the importance of this factor in determining handpiece speeds. It compares the maximum speeds attained with three magnet cylinders and four burs at a series of pressures. The cylinders were all balanced by grinding in the handpiece used for the tests, a Weber AT 200. Note that of the three cylinders, No. 1 which was the slowest running of the three still shows signs of resonance problems and is apparently not fully balanced. It shows a one-third increase in speed between 20 and 30 psi from 180,000 to 240,000 rpm, (both multiples of 60,000), and not until the pressure was increased to 60 psi was any further increase in speed obtained. The other cylinders and the burs showed a continual increase in speed with pressure.

Probably the most significant point relative to this table, however, is that, in spite of their large size (approx. .240 x .400 inch) and the irregular surface produced in the balancing operation, cylinders 2 and 3 ran as fast or faster than any of the burs. This indicates that size alone is no detriment for high speed operation and that air drag must play a very minor role in controlling speed. It also appears that an eccentric bur or worn chuck that unbalances the rotor can result in considerable slowing of the handpiece and reduced performance.

Typical torque-speed curves for the various handpieces tested with resonance effects eliminated are shown in Figure 8. All curves are for 30 psi air pressure which is the approximate maximum pressure allowed by the regulators in the S. S. White and Ritter handpieces tested.

Of the six curves shown, numbers 1, 2, and 6 are for handpieces using latch-type contra-angle burs while the other three handpieces use friction-grip burs. The use of the larger shank, latch-type bur results in a larger overall head size for the handpiece and appears to require a greater air supply. Of the three latch-type handpieces tested, only one, the Weber AT 200 is marketed at the present time. It has replaced the Weber model 700.

The Midwest handpiece studied has been replaced by a friction-grip handpiece which was not tested.

In those cases where several samples of a single handpiece design were tested, considerable differences in performance were noted. In addition, smaller changes occurred from day to day and run to run with a single handpiece. These variations together amount to as much as ± 15% from the mean and appear to be due mainly to such causes as irregular lubrication and bearing wear.

While the torque-speed curve provides the basic information in regard to the energy transferred from the handpiece to the bur, in many cases, it is more informative as well as more convenient to work with power-speed data. Since the power of a rotating device is equal to the product of the speed and torque, the power-speed curve is readily derived from the torque-speed measurements. The power curves corresponding to the runs of Figure 8 are shown in Figure 9. For comparison the belt-driven handpiece of Figure 4 develops a maximum power of 25.9 watts at 19,000 rpm.

The effect of variations in pressure upon the performance of one air turbine handpiece is shown in Figures 10 and 11. The values given are for the Weber AT 200,

which is shown here because of the range of pressures usable with this handpiece. A wide pressure range is definitely advantageous for laboratory investigation since it permits the study of a variety of speeds and powers with a single handpiece.

The clinical necessity for very high pressures is doubtful and some makes of handpieces have regulators which permit a maximum pressure of 30 psi.

The curves of Figures 10 and 11 show certain characteristics common to all of the air turbines tested. The effect of increasing air pressure is much greater upon the torque than upon the speed. As seen in Figure 10, doubling the air pressure will approximately double the maximum torque developed but will increase the maximum speed only 16%. The influence of design appears to be much more important than air pressure in determining maximum handpiece speed. However, the pressure used may make a considerable difference in the speed reached during cutting. Figure 10 indicates that if the handpiece is required to supply five gram-centimeters of torque to the instrument during cutting, (a high value for this speed range), the handpiece will run 270,000 rpm at 60 psi, 240,000 rpm at 50 psi, 205,000 rpm at 40 psi, 135,000 rpm

at 30 psi, and will stall completely at 20 psi.

Figure 11 shows that the maximum power available increases rapidly with increased pressure. The speed at which the maximum power occurs is also seen to increase with pressure.

Unfortunately, from the clinical point of view, information is not yet available as to how much power is needed or desirable for operative use. It is now possible to make a start in that direction by making cutting tests using handpieces whose operating characteristics are known. Provided with the data of Figure 11, it is possible, for example, to make a series of cuts at a constant speed with varying powers (shown by the dots in Figure 11) or at constant power with varying speeds (shown by crosses). Study of the cutting performed and heat produced under these conditions should permit the determination of the effect of both factors upon cutting efficiency. Such a program has been undertaken in the expectation that it will eventually lead to a better understanding of the dental cutting process as a whole.

III. SUMMARY

The operating characteristics of several designs of air turbine handpieces have been investigated. Their ability to transmit energy to the shaft of the cutting instrument was studied by means of an electro-dynamic brake, and was found to be strongly dependent upon the dynamic balance of the instrument and upon the air pressure used. This method provides a means for the comparison of various air turbine handpieces and yields data which can be used as a basis for the study of the mechanism and efficiency of dental cutting procedures.

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Table 1

Air Turbine Handpieces Tested

Handpiece			Number of Samples
Densco	Aero Turbex		1
Midwest	Air Drive		1
Ritter	Air Rotor		2
S.S. White	Air Rotor		1
Weber *	Air Turbine	700	4
Weber	Air Turbine	AT 200	2

Table 2

The Effect of Balancing Upon Maximum Rotational Speed

	Magnet Cylinder		
	1	2	3
Initial Speed	80,000 rpm	50,000 rpm	70,000 rpm
1st Grinding	85,000	75,000	220,000
2nd Grinding	85,000	280,000	50,000
3rd Grinding	320,000	--	210,000

Handpiece	Weber AT-200 Air Turbine
Pressure	30 psi
Cylinder	.240 Diam. x .400 length approx.

Table 3

The Effect of Air Pressure Upon the Rotational Speed of Various Instruments

Instrument	Air Pressure to the Handpiece				
	20 psi	30 psi	40 psi	50 psi	60 psi
Cylinder No. 1	180,000rpm	240,000rpm	240,000rpm	240,000rpm	280,000rpm
Cylinder No. 2	270,000	290,000	300,000	340,000	360,000
Cylinder No. 3	250,000	275,000	280,000	300,000	320,000
No. 700 Bur	180,000	230,000	275,000	290,000	320,000
No. 6 Bur	200,000	225,000	250,000	275,000	280,000
No. 558 Bur	180,000	200,000	225,000	240,000	250,000
No. 35 Bur	240,000	250,000	275,000	290,000	300,000

Cylinder diam. .240 inch length .400

Handpiece Weber AT-200

11-1400

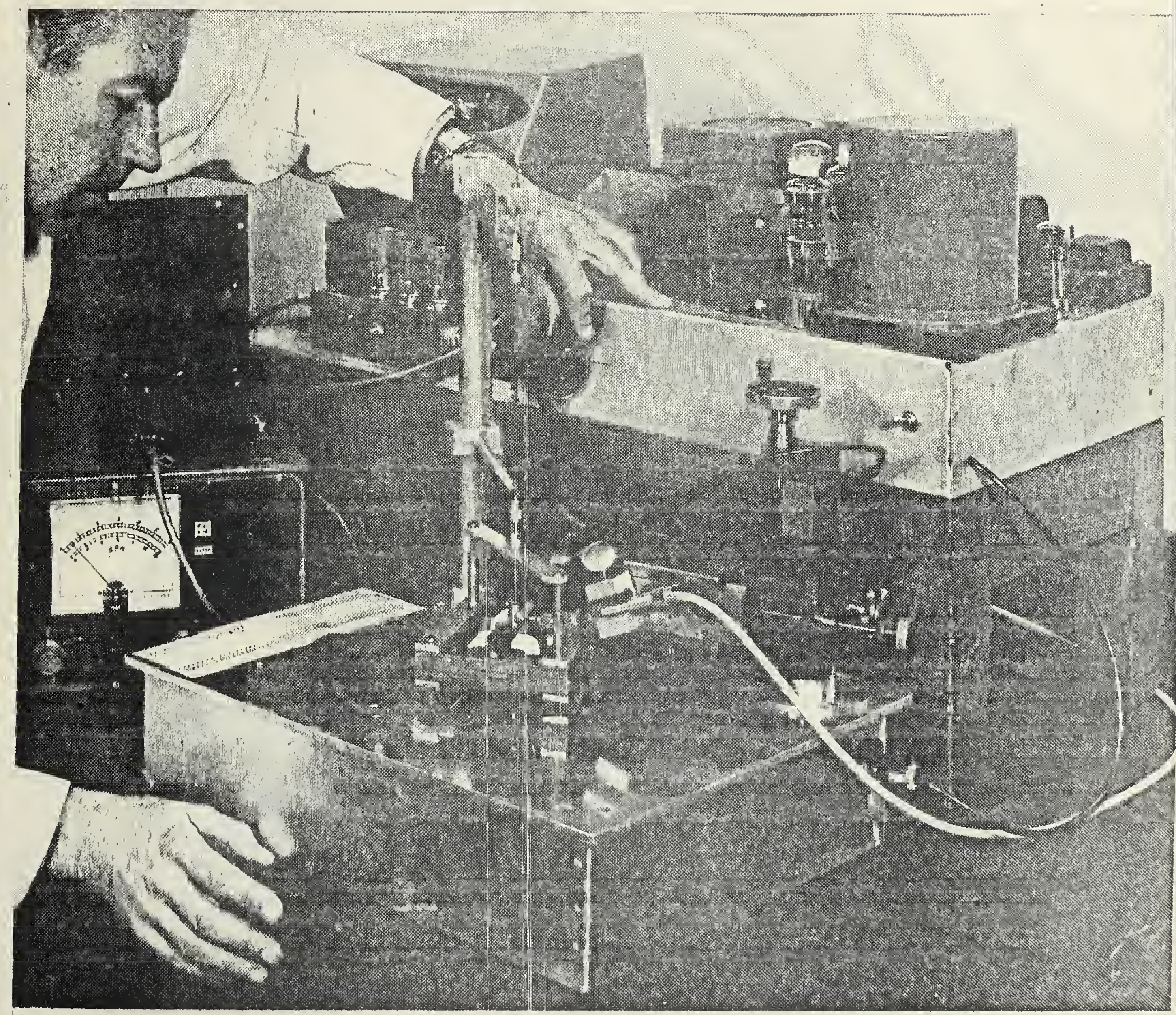

Figure 1. Apparatus employed for the high speed-low torque measurements.

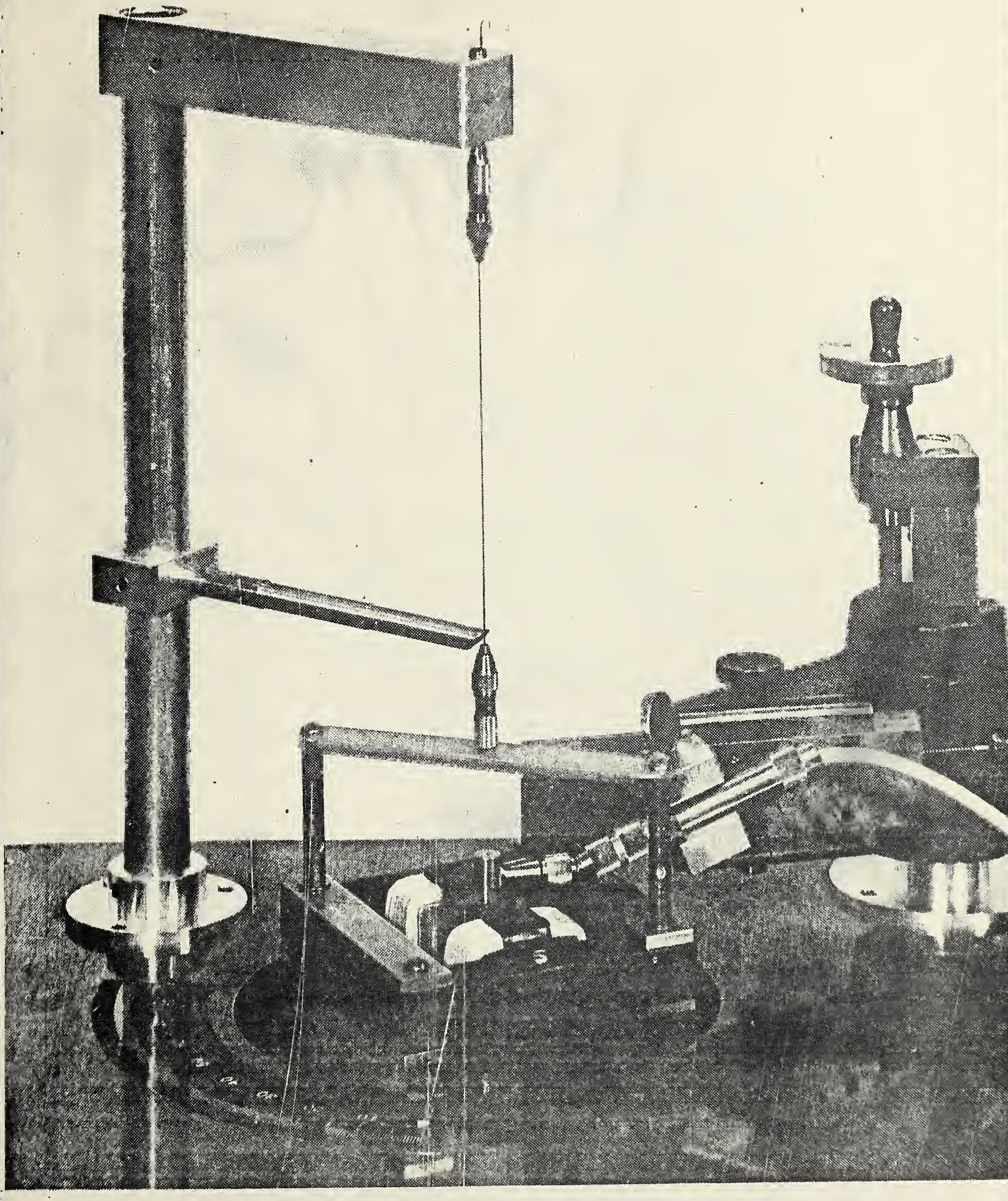

Figure 2. Closeup showing details of the electrodynamic brake.

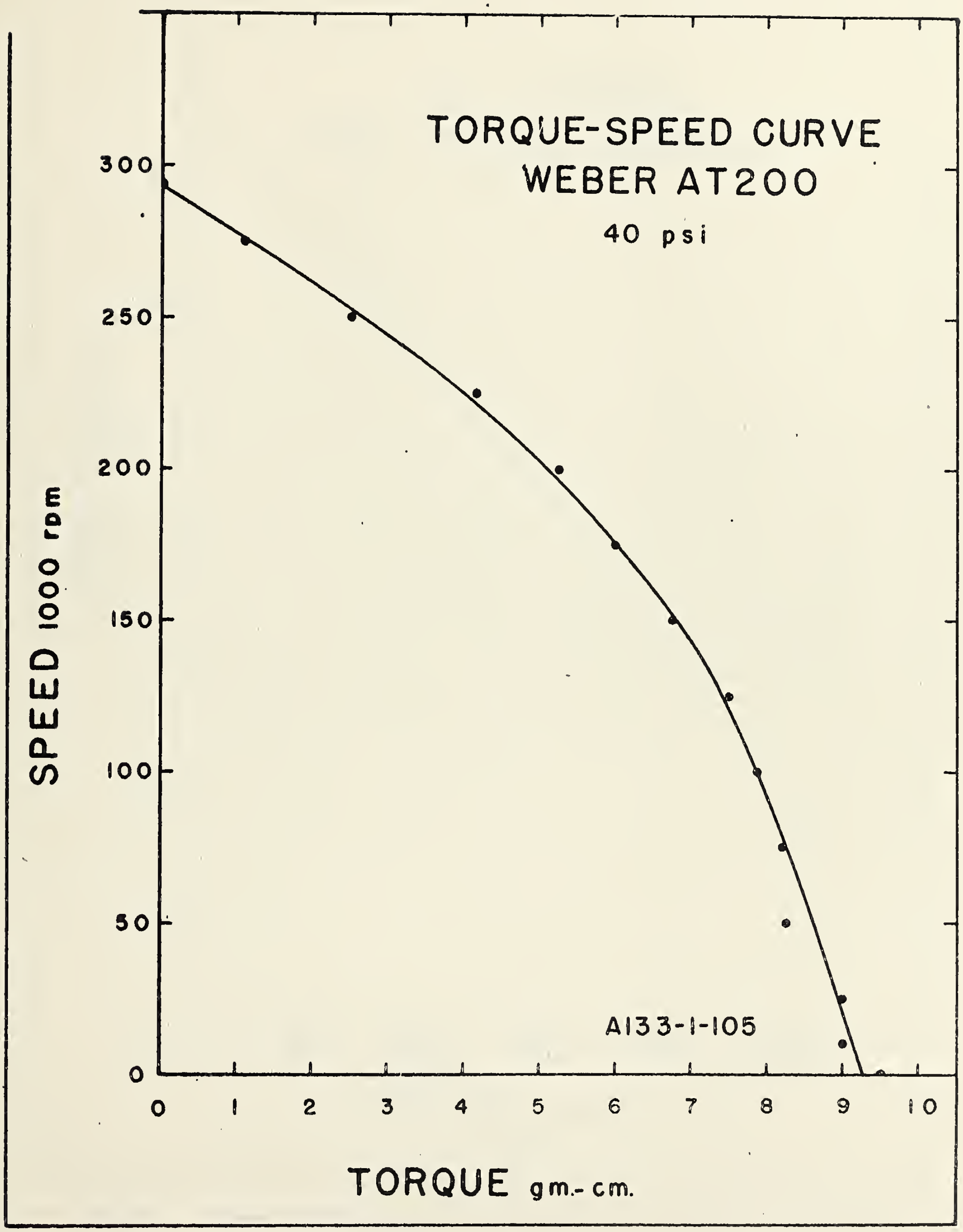

Figure 3. Torque - speed curve typical of air turbine handpieces.

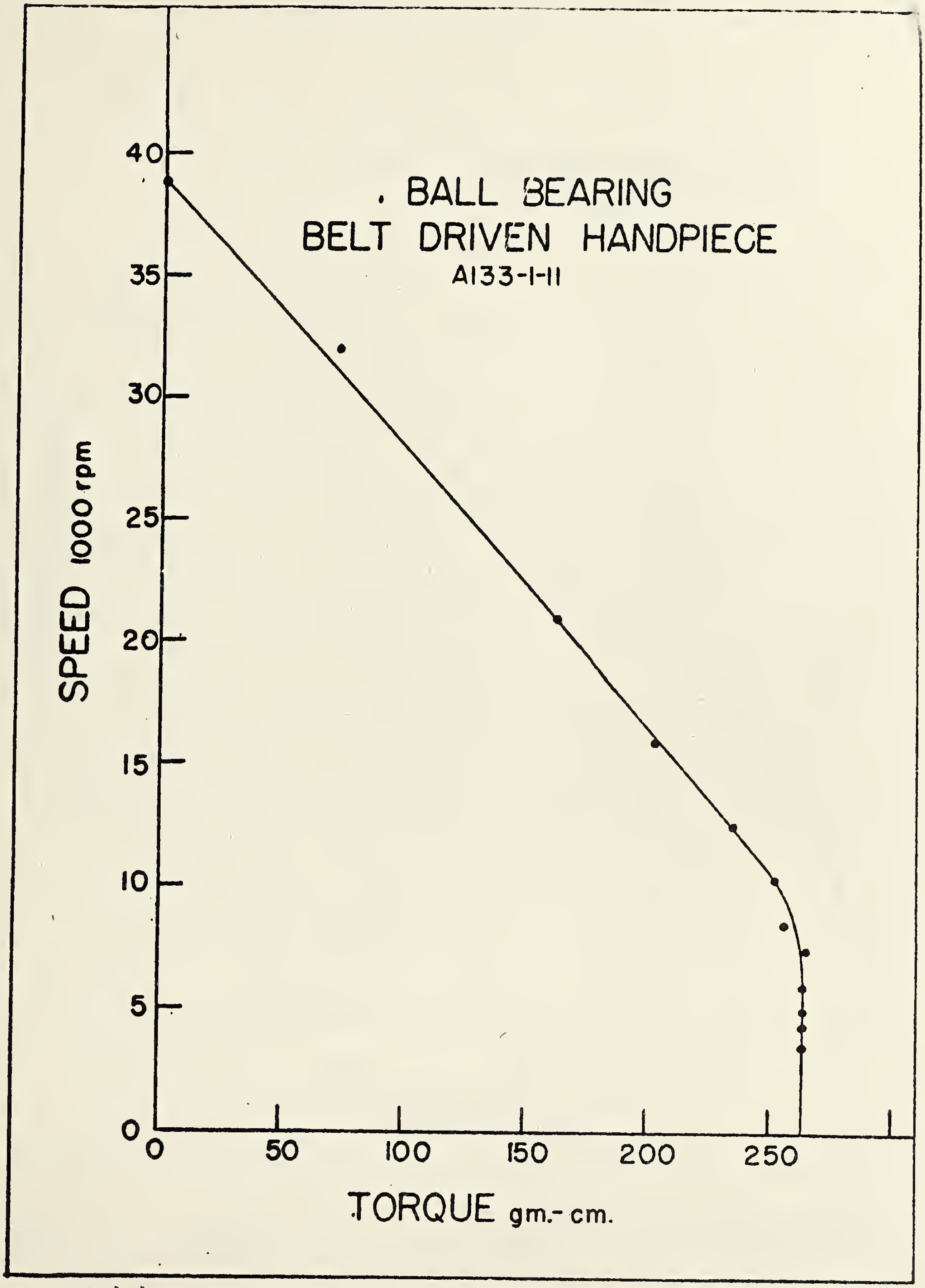

Figure 4. Torque - speed curve for a typical ball bearing belt driven handpiece.

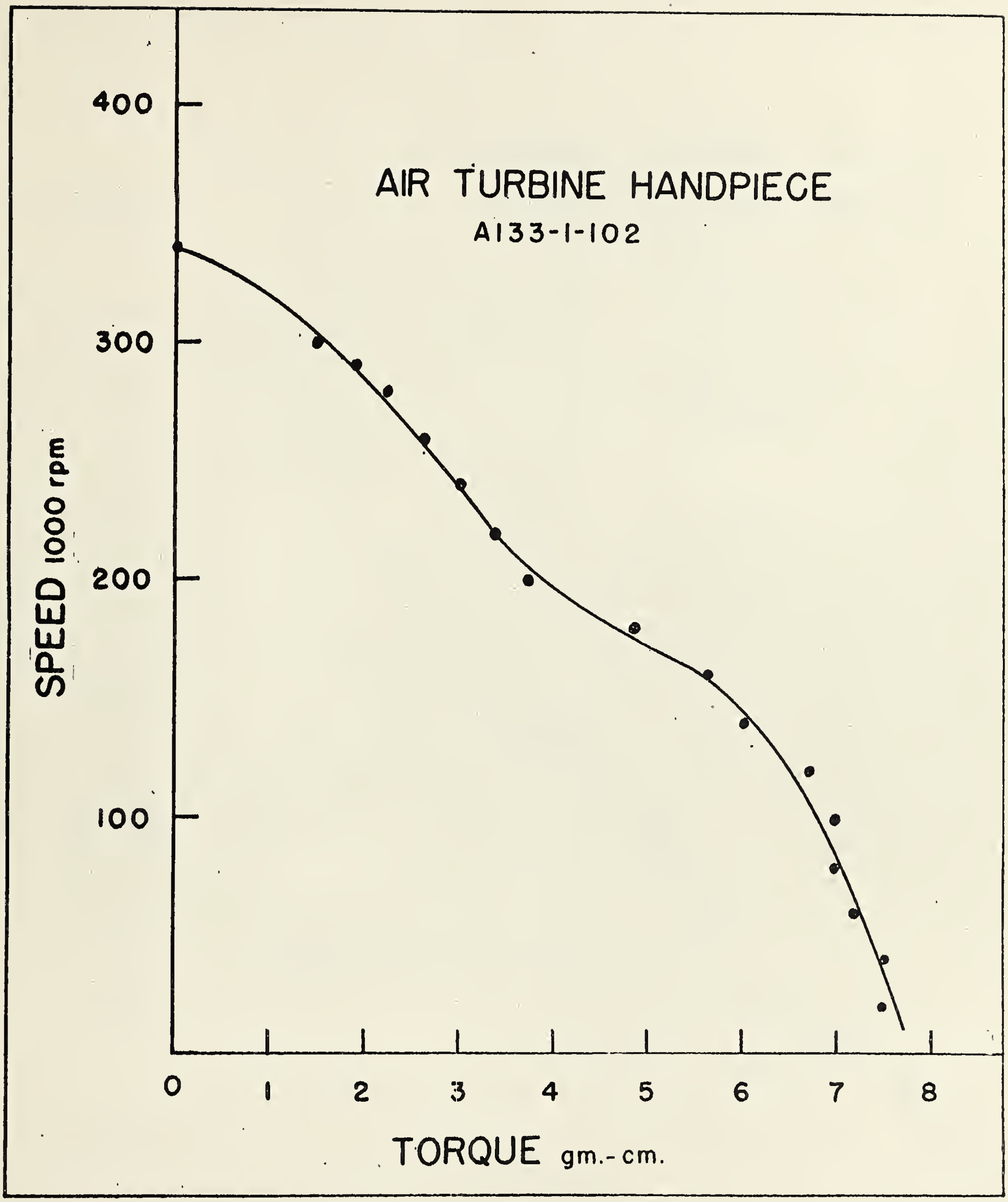

Figure 5. Torque - speed curve showing mild resonance effects.

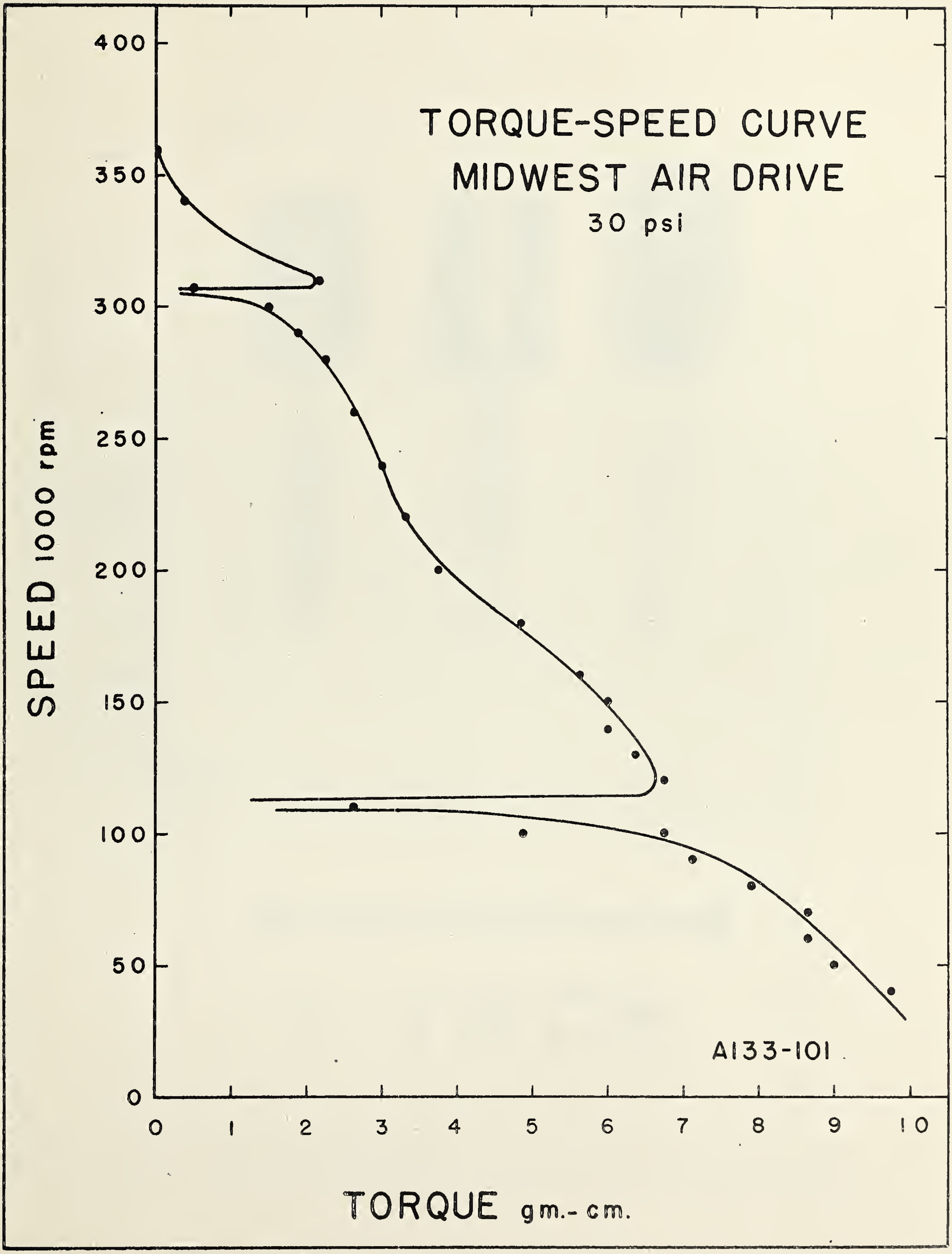

Figure 6. Torque - speed curve showing extreme resonance effects.

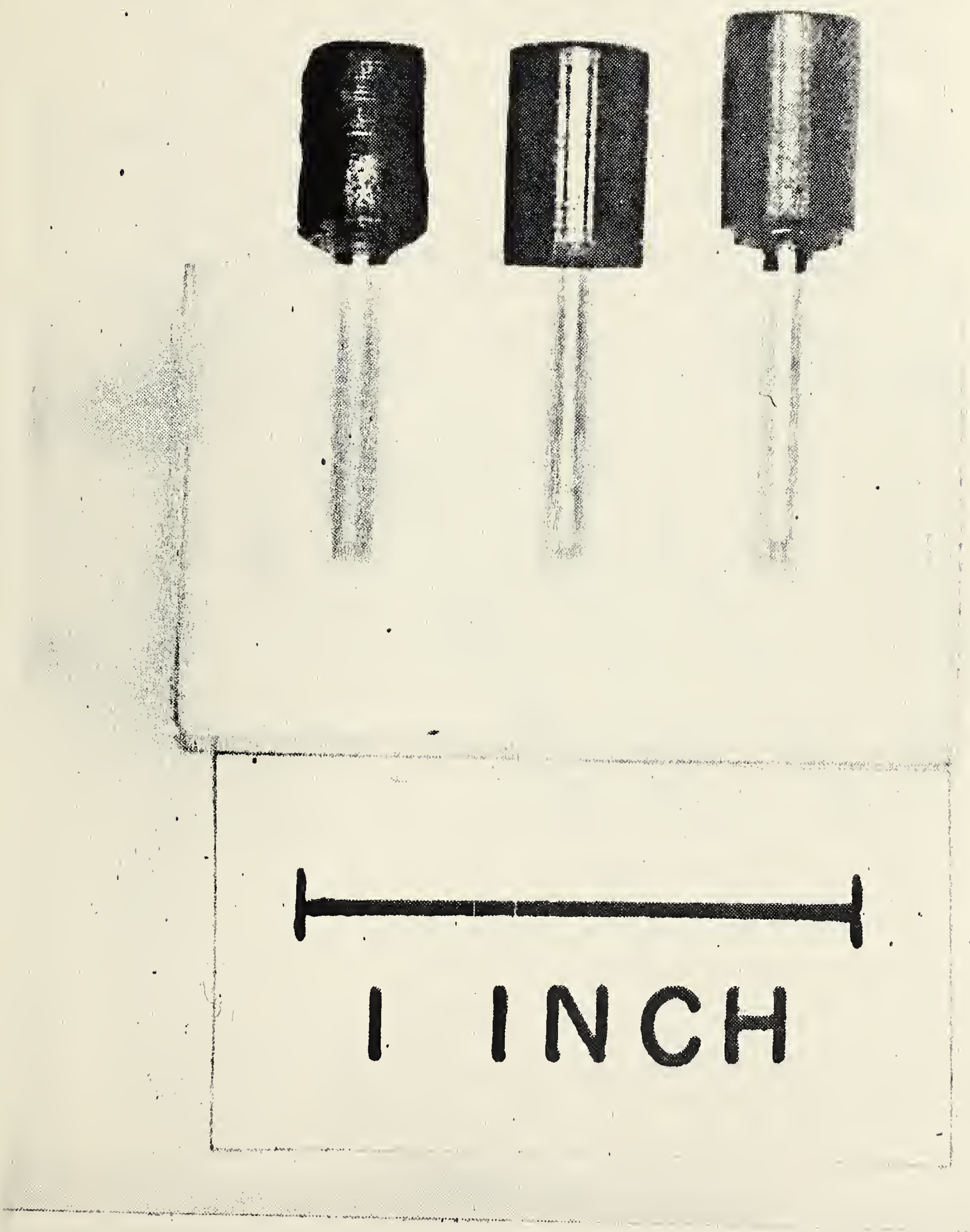

Figure 7. View showing the effect of grinding for dynamic balancing upon the shape of magnet cylinders.

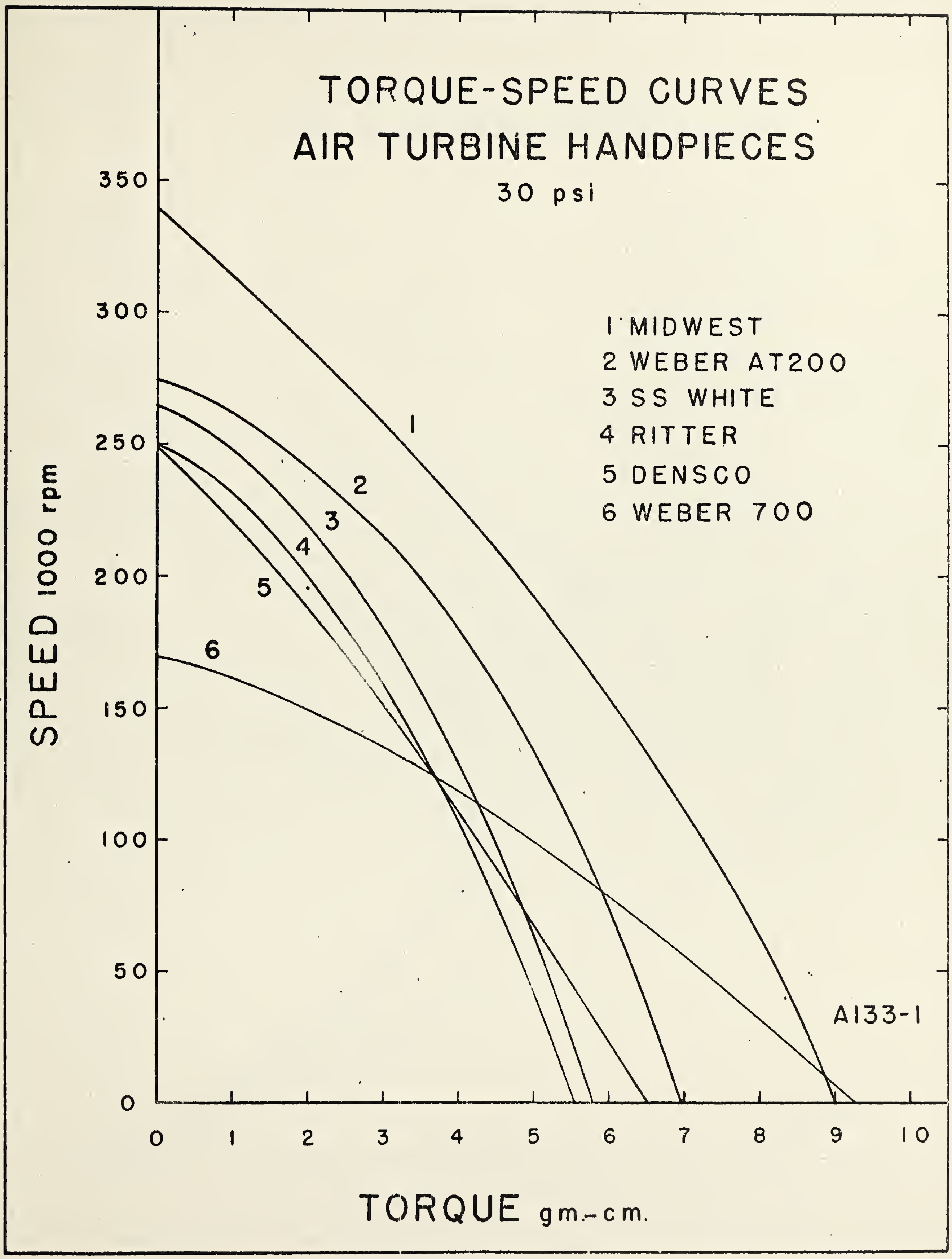

Figure 8. Torque - speed curves for various air turbine handpieces at 30 psi air pressure.

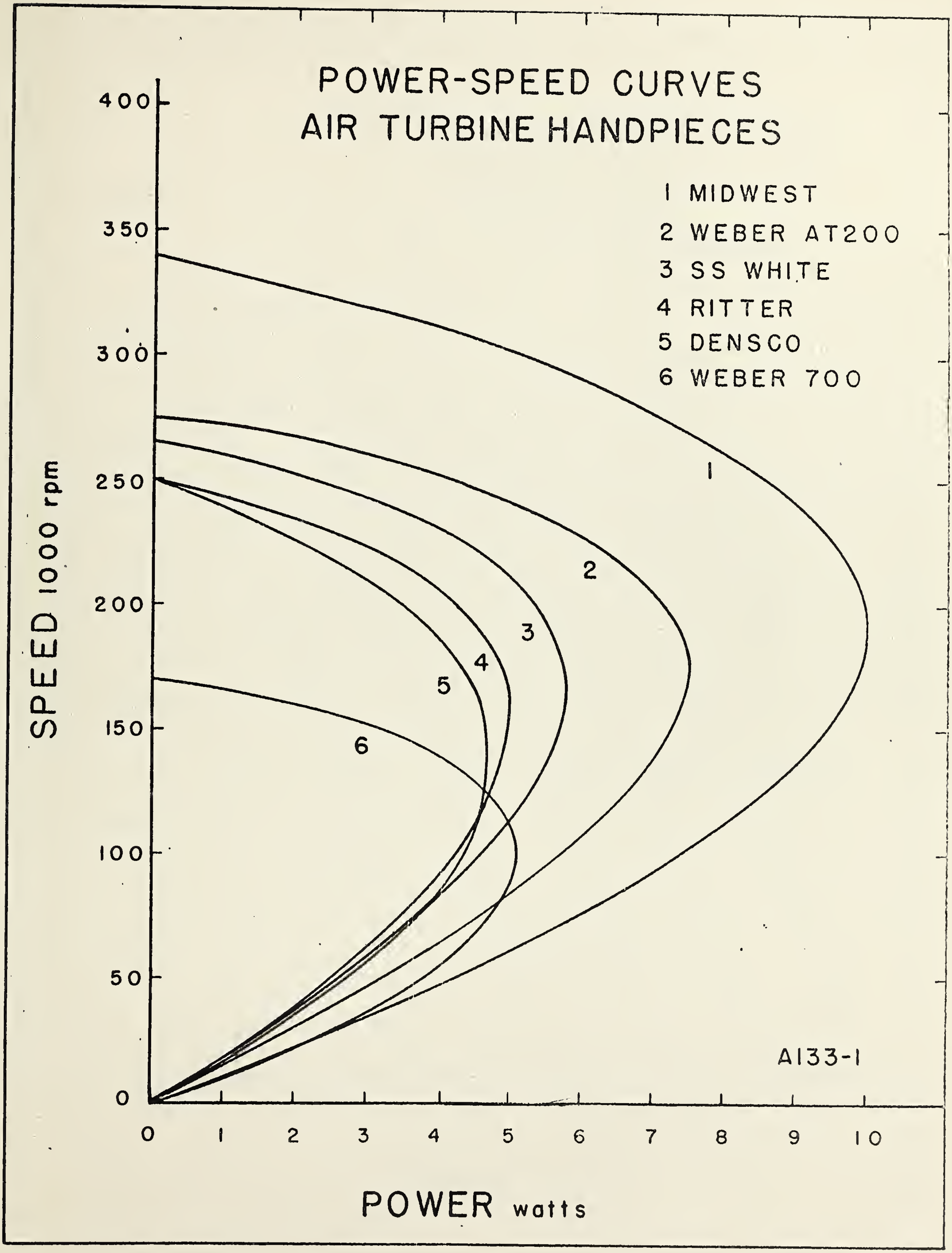

Figure 9. Power - speed curves for various air turbine handpieces, derived from the data of Figure 8.

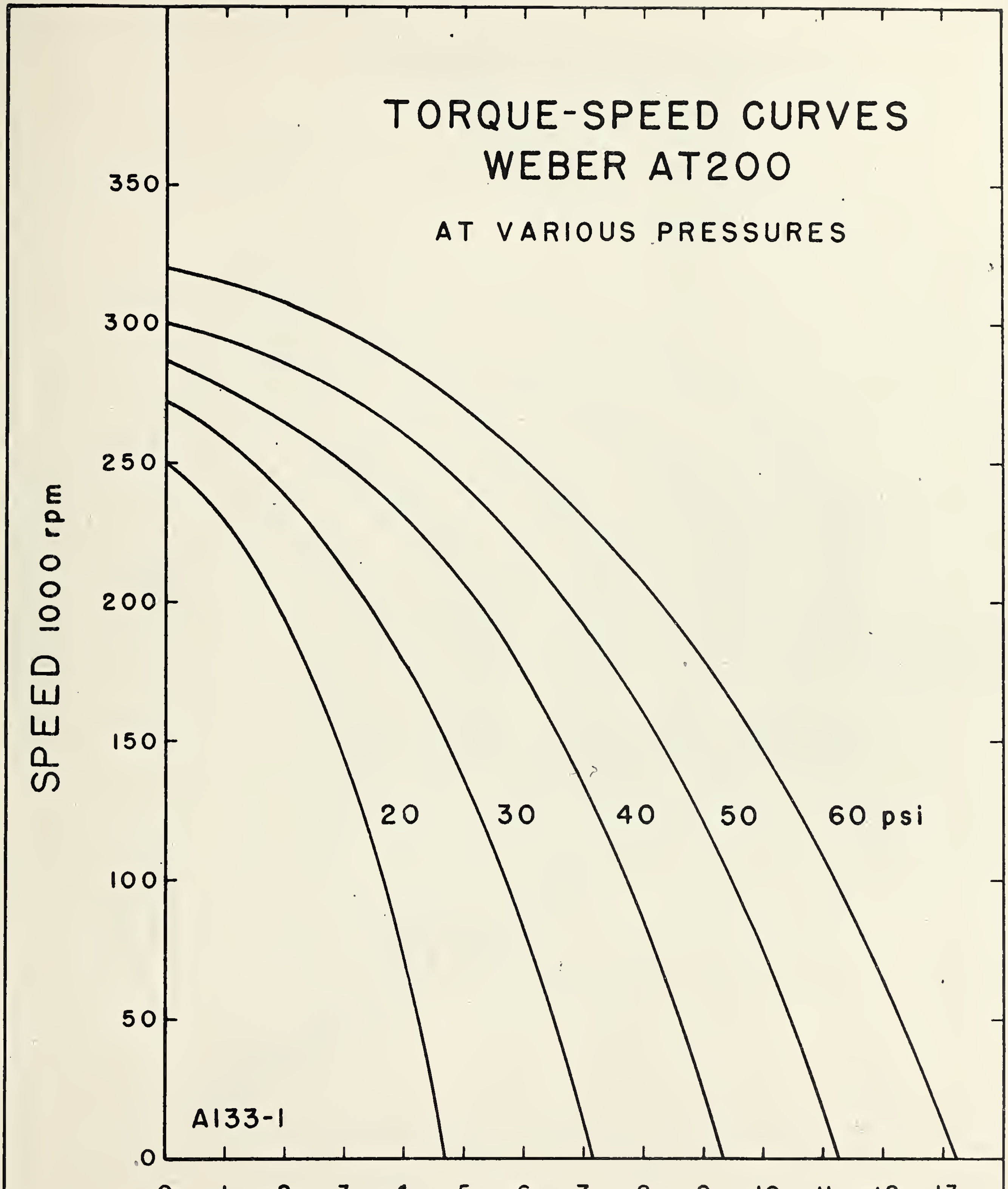

Figure 10. Torque - speed curves showing the effect of variation in air pressure.

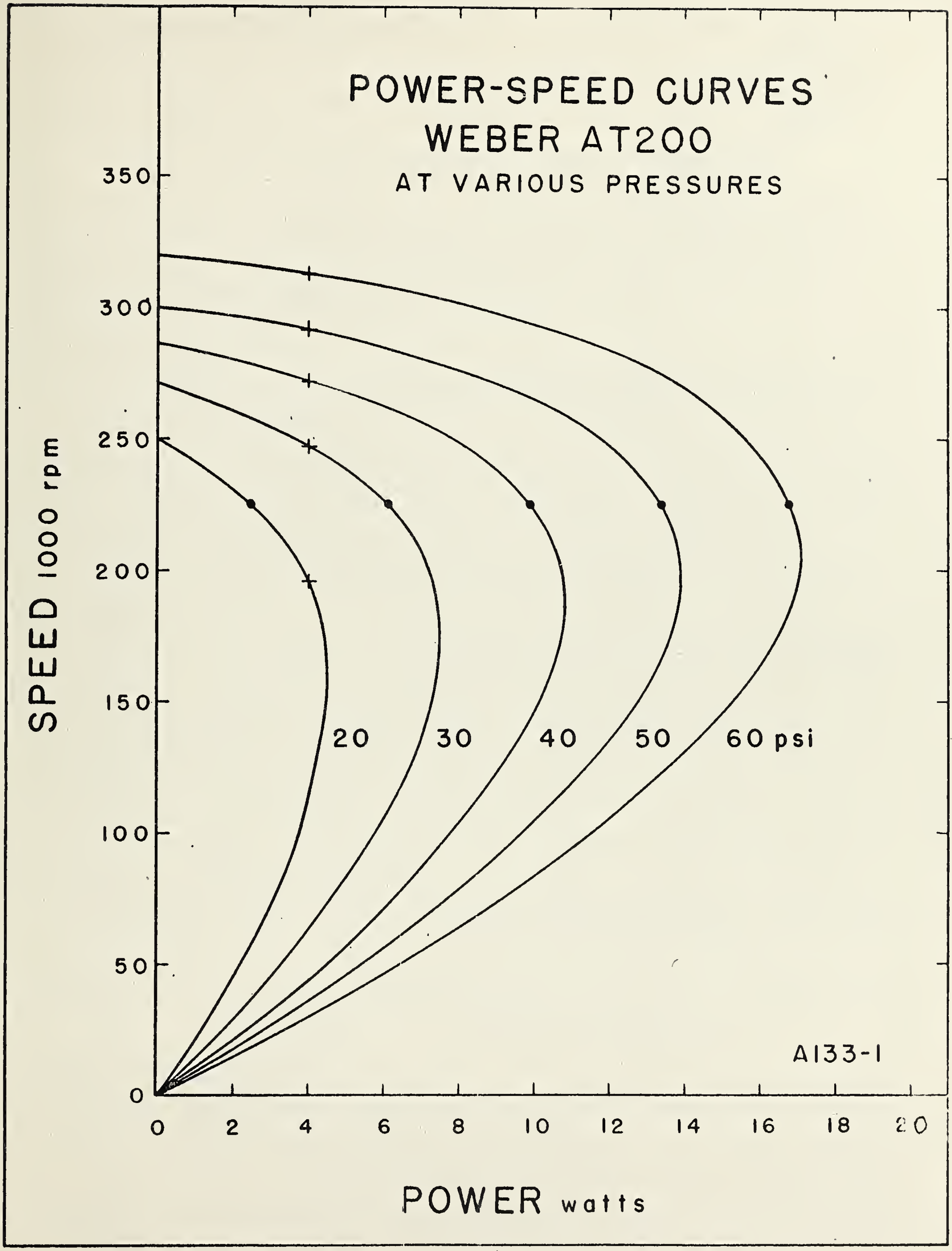

Figure 11. Power - speed curves showing the effect of variation in air pressure.

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