THE POWER REQUIRED TO DRIVE SPOKE AND DISK WHEELS AND PULLEYS.

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Some years ago the senior author of this paper, while working on a problem requiring a high peripheral velocity of a wheel or disk, found that the power required to drive a wire spoke bicycle wheel increased with surprising rapidity with increase in rotational speed. He found it impossible with the power at his command to drive a bicycle wheel at the desired speed. A steel disk (a circular saw disk) was readily driven at a much higher speed. This suggested a study of the comparative power required to drive spoke and disk wheels and pulleys.

An automobile axle was removed from its housing and mounted to run in two plane bearings mounted on a massive wooden framework to minimize vibration. The axle was driven by means of a variable speed motor of the type in which the armature is movable longitudinally in the field, thus giving *any* desired speed between wide limits. The axle speed was determined by means of a Van Sicklen tachometer, and for convenience in calculation was adjusted in each case to multiples of 100 r.p.m. The shaft was carefully lined up in the bearings and was driven at high speed for several days before any observations were taken. Spoke and disk wheels carrying 32"x3" tires were alternately mounted on the axle and rotated at the speeds indicated in the table. The power required to drive the axle was computed from the terminal voltage and the line current. This, of course, neglects the power lost in the motor itself. However, the study was intended to be comparative only.

TABLE I.—POWER REQUIRED TO DRIVE SPOKE AND DISK AUTOMOBILE WHEELS

Revolutions per minute	Miles per hour	Disk Wheel Watts	Spoke Wheel Watts	Difference Watts	Difference H. P. 4 wheels
400	39	300	330	30	0.16
600	58	370	430	60	0.32
800	78	456	572	106	0.57
1,000	98	540	740	160	0.86
1,200	118	720	950	250	1.34
1,400	137	890	1,280	390	2.09
1,600	157	1,190	1,760	570	3.06
1,800	176	1,500	2,390	890	4.77

Neither of the two automobile wheels was balanced well enough to permit of very high rotational speeds without dangerous vibration.

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After mounting on the axle each was carefully balanced on horizontal knife edges, the spoke wheel requiring much more adjustment than the disk wheel. Even after being adjusted with considerable care, two or three accidents occurred. One was due to the fact that after inflating the tire (to 40 pounds in each case) the writers forgot to put on the valve cap. At a speed near the maximum shown in the table the centrifugal force on the valve plunger opened the valve and permitted the air to escape from the tire. The wheel then threw the tire which, after rebounding from a concrete wall, struck and demolished a twenty-four inch iron pulley on a line shaft.

Several observations were made at each speed shown in table I, and at numerous speeds not recorded. The results given in the table are sufficient to enable us to plot the curves D and S in figure 1, from which the power required for other speeds can be easily determined. D is the power curve for the disk wheel and S for the spoke wheel.

Column 2 of the table gives the speed in miles per hour corresponding to the r.p.m. of the first column, and the last column gives for each speed the extra horse power required to drive four spoke wheels over that required to drive four disk wheels of the same size.

The writers realize that the air friction losses in the case of a wheel rotating on a stationary axis can not be assumed equal to the losses where the axis too is moving. In the case of the stationary axis a body of air about the wheel is thrown into rotary motion, with the result that the air friction loss is less than if the air were at rest. Anything that tends to prevent the air from acquiring this rotary motion increases the air friction losses. When a spoke wheel was rotated inside a wooden box with the sides of the box within a few inches of the wheel, the driving power required to produce a given rotational speed was greatly increased and the temperature of the air in the box rose rapidly. Certainly the air friction losses shown in the last column of table I are not greater than would occur in the case of a spoke wheel automobile moving at the speeds indicated in the second column. It would appear then that the disk wheel has little advantage over the ordinary wood spoke wheel at ordinary automobile speeds. But at the speed at which long distance auto races are usually run—ninety to one hundred miles per hour—air friction losses for spoke wheels are about one horse power more than for disk wheels. This loss, by no means negligible, increases rapidly at higher speeds.

The results in the table are for plain spoke wheels such as are used on light cars. The heavier the spokes the greater the air friction losses. For staggered spokes the loss is still greater. It is very much greater for wire wheels.

If one stands near a pulley rotating rapidly he readily perceives the air currents produced, chiefly due to the fact that the spokes or arms of the pulley act like the blades of a fan. In some cases these air currents may be desirable, for ventilation, cooling, or something of the kind. But if they are not useful they are wasteful in that power is required to produce them. They can be greatly reduced by using web, instead of spoke pulleys, or by placing a tightly fitting flat circular disk in each end of the pulley so as to enclose the spokes. In the experiment which follows the disks were made of a thick and firm cardboard—called "beaver board".

Seven light cast iron pulleys were mounted on a line shaft some twenty feet long. The shaft was driven by the variable speed motor used in the wheel experiment. One of the pulleys was 30x4.5 inches, four were 24x4, one was 20x4, and one 16x4 inches, all having six spokes. The spokes were elliptical, thin and almost flat, a form designed to minimize air resistance. Notwithstanding this fact, the power required to drive the shaft was noticeably lessened when the spokes were covered with beaver board disks.

Table II gives the power required to drive the shaft at speeds between 300 and 800 r.p.m., when all the pulleys were open, spokes or arms exposed—and when all were closed by means of card board disks, spokes enclosed. A plot of some of the results gives the curves O and C of figure 1, the former for open pulleys, the latter for closed pulleys.

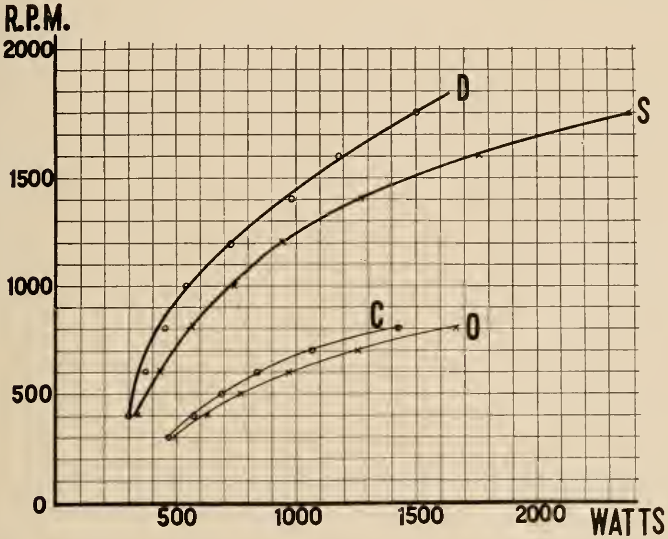

Fig. 1. Results of experiments to determine the power required to drive disk and spoke wheels and pulleys. D, power curve for disk wheel; S, for spoke wheel; C, for pulleys with spokes covered; O, for pulleys with spokes open.

The results tabulated are for two cases only—all pulleys open, all closed. Observations were made by measuring the driving power required for all the speeds tabulated—first with all the pulleys closed, then with one open, then two open, and so on to the last series, when all the pulleys were open; that is, all the disks had been removed. The driving power increased slightly every time a pair of the protecting disks was removed.

Inspection of table II and curves O and C shows the web pulley at moderate speeds has little advantage over the spoke pulley of the type used. But at the higher speeds the difference is a matter worth considering, particularly if a large number of pulleys are in operation. For instance, the seven pulleys in this experiment running at 800 r.p.m. required .32 h.p. less when the spokes were enclosed than when they were exposed. Figuring on the basis of one cent per horse power hour, for ten hours per day and 300 days per year, the saving per year would be $9.60, an average of $1.37 per pulley.

TABLE II.—POWER REQUIRED TO DRIVE SPOKE AND WEB PULLEYS

Speed r. p. m.	All pulleys open	All pulleys closed	Difference in watts	Difference in h. p.
300	490 watts	478 watts	12 watts	0.01
350	560	533	27	0.03
400	625	577	48	0.06
450	700	640	60	0.08
500	775	695	80	0.11
550	870	760	110	0.15
600	980	840	140	0.19
650	1,105	950	165	0.22
700	1,260	1,080	180	0.24
750	1,440	1,135	205	0.27
800	1,660	1,420	240	0.32

In considering the air friction losses of the two types of pulleys, one should note that the spoke pulleys used in the experiment were of the type designed to minimize air friction losses. Heavier and thicker spokes increase the loss, double arm pulleys greatly increase it, and wide flat armed pulleys, such as the usual wood split pulley, very greatly increase it. There is no question as to the economy of enclosing the arms of any wide face and therefore wide armed wood split pulley that is to be operated at high speed. The data of a single experiment will verify this statement.

A wood pulley 12 inches in diameter with flat 6-inch face and having four flat spokes or arms 4.5 inches wide was mounted on an extension of the motor shaft of a standard one-half horse power A.C. motor supported by ball bearing trunions and weighted so as to be in balance in any position. Concentric with the shaft and attached to the motor frame was mounted a grooved pulley five inches in diameter over which a cord passed to a sensitive spring balance, which gave the torque required to hold the motor in a given position against the armature reaction.

When the open pulley was driven at a speed of 1,840 r.p.m. the torque was 3.375 lbs. When the pulley was closed with a cardboard disk at each end and rotated at 1,850 r.p.m., the torque was .25 lb. It will be observed that the torque in the case of the open pulley was more than thirteen times the torque when the pulley ends were closed. The horse power in each case was as follows:

Open pulley, 1,840 r.p.m.	0.2463 h.p.
Closed pulley, 1,850 r.p.m.	0.0183 h.p.
Difference in favor of closed pulley	0.228 h.p.

Note that the air friction losses in the case of this flat spoke 12x6 wood pulley running at 1,840 r.p.m. were greater than the losses for all seven of the narrow face cast iron pulleys running at 650 r.p.m. This is due in part to the fact that the wood pulley was run at a higher rotational speed. However, the peripheral speed was not much higher than in the case of the cast iron pulleys of larger diameter.

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