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ENERGY LOSS AND EFFICIENCY OF POWER TRANSMISSION BELTS

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ABSTRACT

A comprehensive selection of belt type and construction from industrial and agricultural applications is extensively tested and compared for idling loss and power transmission efficiency. Data is documented for Vee, joined-V, V-ribbed, and synchronous belt types and for cogged, plain, and laminated V-belt constructions. The level of energy savings achieved by the replacement of plain-base wrapped V-belts with cogged V-belts is emphasized. Belt efficiency, slip, and temperature dependence on the basic drive parameters of torque, sheave diameter, belt tension, and contact angle is reported.

INTRODUCTION

Power transmission efficiency and parasitic idling losses in belt machine elements have been considered for over 50 years. Most references cite efficiencies between 90 and 98 percent for various belts with 95 percent being a typical value [1-11]. Experimental data, however, for the current spectrum of belt types, constructions, and application conditions is not generally available. In order for the design engineer to assess system energy loss, detailed effects of belt construction and drive parameters become necessary. Consequently, the purpose of this investigation is to experimentally survey belt efficiency in the major industrial and agricultural applications.

Energy comparisons are documented for all the principal belt categories consisting of Vee, joined-V, V-ribbed, and synchronous types. Particular emphasis is given to the energy savings aspect of the cogged construction.

EXPERIMENTAL SYSTEM

Idling loss and belt efficiency are determined by separate experimental approaches. Due to the wide difference between small parasitic losses and large application power levels, a more sensitive direct measurement of idling loss is employed, while transmission efficiency is computed from simultaneous input and output power measurements.

Idling losses are monitored with a 10 watt least-count precision digital Wattmeter wired to either a 1 horsepower, 3500 RPM or a .5 horsepower, 1660 RPM AC motor. The motor in turn is connected to a .75 inch idling jack shaft by means of the test belt. Motor losses while running without a belt are measured and subtracted from the Wattage consumed by the motor, belt and jack shaft system. Bearing losses are found to be less than the 10Watt least count, and are included as part of the belt idling loss.

Power transmission efficiency at rated and representative application power levels for the larger belts is measured with the dynamometer system in Fig. 1. The system is digitally instrumented with trunnion mounted 10,000 pound-inch pyrometers, and a tension load cell. The lower power levels of the smaller belts require a more sensitive measuring system which entails a lower capacity prime mover and absorber with a 500 pound-inch torque cell.

EFFICIENCY COMPARISONS

Industrial and agricultural belt types and constructions are depicted in Fig. 2. Within each category Vee, V-ribbed, and synchronous cross sectional dimensions are representative of primary Applications. Belt constructions include cogged, plain heavy duty, laminated, and central neutral axis. Sizes range from .380 to 2.25 inches in width, .25 to .75 in thickness and 45 to 120 in length with cord diameters from .037 to .100 inches.

IDLING LOSS

Idling power losses for industrial cross sections are listed in Table 1 as averages of generally two tests having repeatability within the 10 Watt least count. Loss dependence on tension, diameter, speed, and width is displayed in Fig. 3.

The tension effect results from frictional sliding as a belt enters and exits a pulley; whereas, the diameter dependence is a consequence of bending hysteresis as a belt flexes from straight span to curved pulley paths. Since pulley speed controls the rate of frictional and hysteretic energy dissipation, it is essentially proportional to power loss. The influence of belt width is due to both increased frictional and bending losses resulting from multiple industrial belts, larger industrial V-belt cross sections, and wider V-ribbed and synchronous belts.

Bending hysteresis is the principal factor determining power loss comparisons between cross sections. Consequently, due to increased flexibility over plain base belts industrial V-belt cogged constructions require the least energy and run at lower temperatures under no load. Reduced cogged hysteresis is reflected by the lower temperature, although enhanced heat transfer from tooth turbulence and greater convective area is an additional factor. For similar reasons, especially reduced thickness, V-ribbed and synchronous belts are characterized by progressively less idling loss and cooler temperature.

Two industrial belts exhibit twice the loss of a single operating at the same tension per belt. A joined V-belt has about the same loss as two single belts in a cogged construction, but the wrapped joined-V shows significantly more loss than two single wrapped belts.

POWER TRANSMISSION EFFICIENCY

Industrial accessory: Energy loss during power transmission at industrial rating application levels is listed in Table 2. Effect of drive torque, diameter, tension, and pulley contact is shown in Fig. 4 for industrial cogged and wrapped B-section belts. Number of tests for each condition range from 4 to 100 with each result averaged over the final three minutes of a half hour period, during which 320 torque measurements are obtained. Repeatability is indicated by a standard deviation of one per cent within the same B-section belt and two per cent between B-section belts of identical constructions.

Tabulated transmission losses of industrial A and B-section belts from Table 2 along with industrial Vee and V-ribbed belts are approximately 75 percent accounted for by the idling losses listed in Table 1; whereas, idling loss accounts for about 50 percent of the synchronous belt transmission losses. Lower cogged idling hysteretic loss is the primary explanation for the B cogged to wrapped efficiency advantage shown in Fig. 4, and is the reason the advantage is maximum at smaller diameters. The cogged belts demonstrated lower slip level further augments its efficiency and temperature performance. Industrial Vee and V-ribbed belts, sizes and constructions are compared for varying diameters with V-ribbed and cogged advantages being greatest at smaller diameters. The accessory belts temperature performance is presented as a function of slip and torque levels.

Agricultural variable speed: Efficiency, slip, and temperature characterize the performance of large agricultural belts employed in the demanding propulsion and grain separation applications of high capacity combines. Testing levels ranged to 150 horsepower corresponding to peak field conditions.

As shown in Fig. 6, both cogged and wrapped belts exhibit efficiencies above 90 per cent, although cogged belts generally display higher efficiency, lower slip, and cooler temperatures. Cogged efficiencies are above 94 per cent throughout the application power range.

CONCLUSIONS

Median efficiency of the surveyed industrial and agricultural belt types and constructions is 96 per cent. Within rated and application power levels, efficiency ranges from 90 to 99 per cent depending on belt type, construction, and application parameters. Both median and range agree with historical data.

The major portion of belt energy loss during power transmission is attributed to parasitic bending hysteresis and sliding friction. The cogged construction which minimizes the hysteretic component of parasitic loss yields the greatest efficiency in each industrial test. The condition of classical B-section cogged belts operating on 3.4 inch diameters at rated power levels demonstrated the largest energy savings, ranging from 3 to 6 per cent.

ACKNOWLEDGEMENT

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Regenerative Industrial Drive System

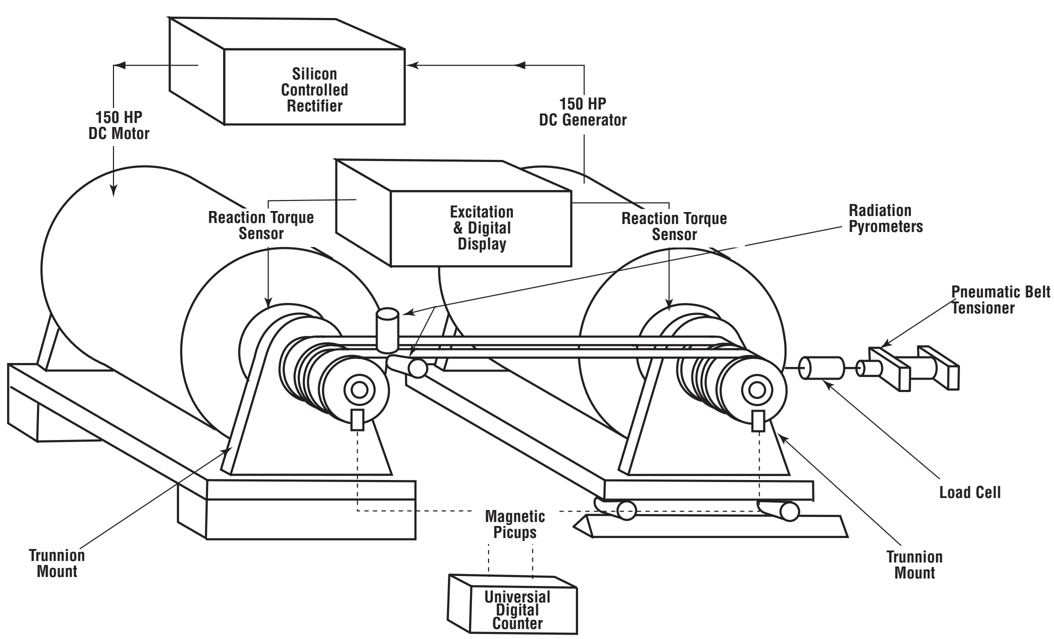
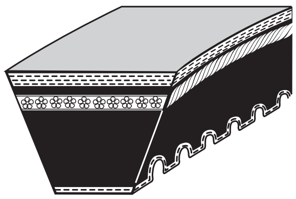


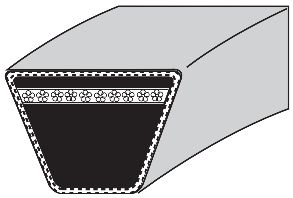
Fig 1. Instrumented Belt Test Dynameter

Fig. 2 Belt Types and Constuction

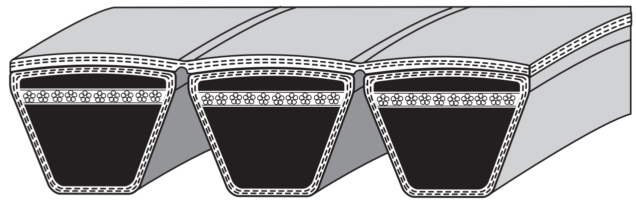
INDUSTRIAL BELTS



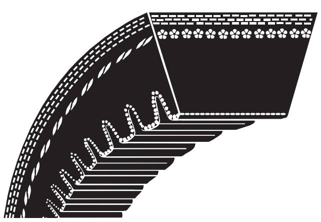
Cogged Belt



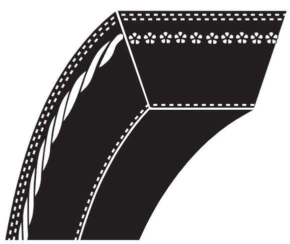
Wrapped Belt



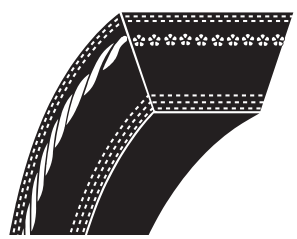
Joined Belt



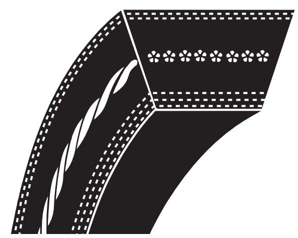
Cogged Belt



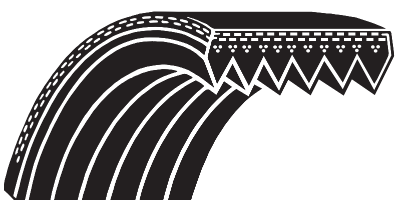
Plain Heavy Duty



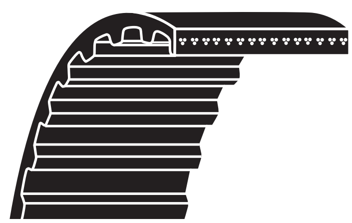
3-Ply Laminated



Centeral Neutral Axis



V-Ribbed Belt



Synchronous Belt

Table 1 Idling Power Loss																	
	4.75 Nominal Diameter (In.)										2.75 Nominal Diameter (In.)						
Belt Cross Section	3500 RPM										3500 RPM				1660 RPM		
		50 Total Tension (LBS)			100 Total Tension (LBS)			150 Total Tension (LBS)			100 Total Tension (LBS)				100 Total Tension (LBS)		
	DR and DN Pitch Dia (In)	Power Loss Watts	Power Loss HP	Temp Above Ambient (ºF)	Power Loss Watts	Power Loss HP	Temp Above Ambient (ºF)	Power Loss Watts	Power Loss HP	Temp Above Ambient (ºF)	DR and DN Pitch Dia (In)	Power Loss Watts	Power Loss HP	Temp Above Ambient (ºF)	Power Loss Watts	Power Loss HP	Temp Above Ambient (ºF)
INDUSTRIAL																	
Classical-V																	
A	4.6	164	.22	28	176	.24	30	223	.30	36	3.0	214	.29	38	110	.15	33
A Cog		93	.12	17	133	.18	18	166	.22	27		132	.18	25	76	.10	24
2A		--	--	--	243	.33	43	315	.42	48		305	.41	44	151	.20	42
2A Cog		--	--	--	177	.24	21	207	.28	24		192	.26	24	86	.12	20
B	5.0	216	.29	34	250	.34	46	298	.40	46	3.4	262	.35	54	149	.20	44
B Cog		120	.16	18	168	.23	19	214	.29	32		183	.25	28	94	.13	25
2B		--	--	--	365	.49	44	487	.65	59		373	.50	60	195	.26	50
2B Cog		--	--	--	223	.30	25	273	.37	31		237	.32	31	125	.17	27
B Wrapped Joined-V, 2-Rib		--	--	--	490	.66	53	552	.74	63		521	.70	59	277	.37	46
B Cog Joined-V, 2-Rib		--	--	--	245	.33	24	269	.36	26		241	.32	29	131	.18	21
Synchronous																	
L038	4.775	32	.04	5	49	.07	7	81	.11	12	2.387	48	.06	16	29	.04	13
L075		41	.05	6	53	.07	8	70	.09	10		53	.07	14	28	.04	10
H050	5.093	61	.08	8	67	.09	10	92	.12	10	2.546	68	.09	19	36	.05	13
H075		76	.10	11	98	.13	12	105	.14	14		90	.12	22	44	.06	15
H100		84	.11	11	113	.15	14	138	.18	16		112	.15	28	47	.06	15

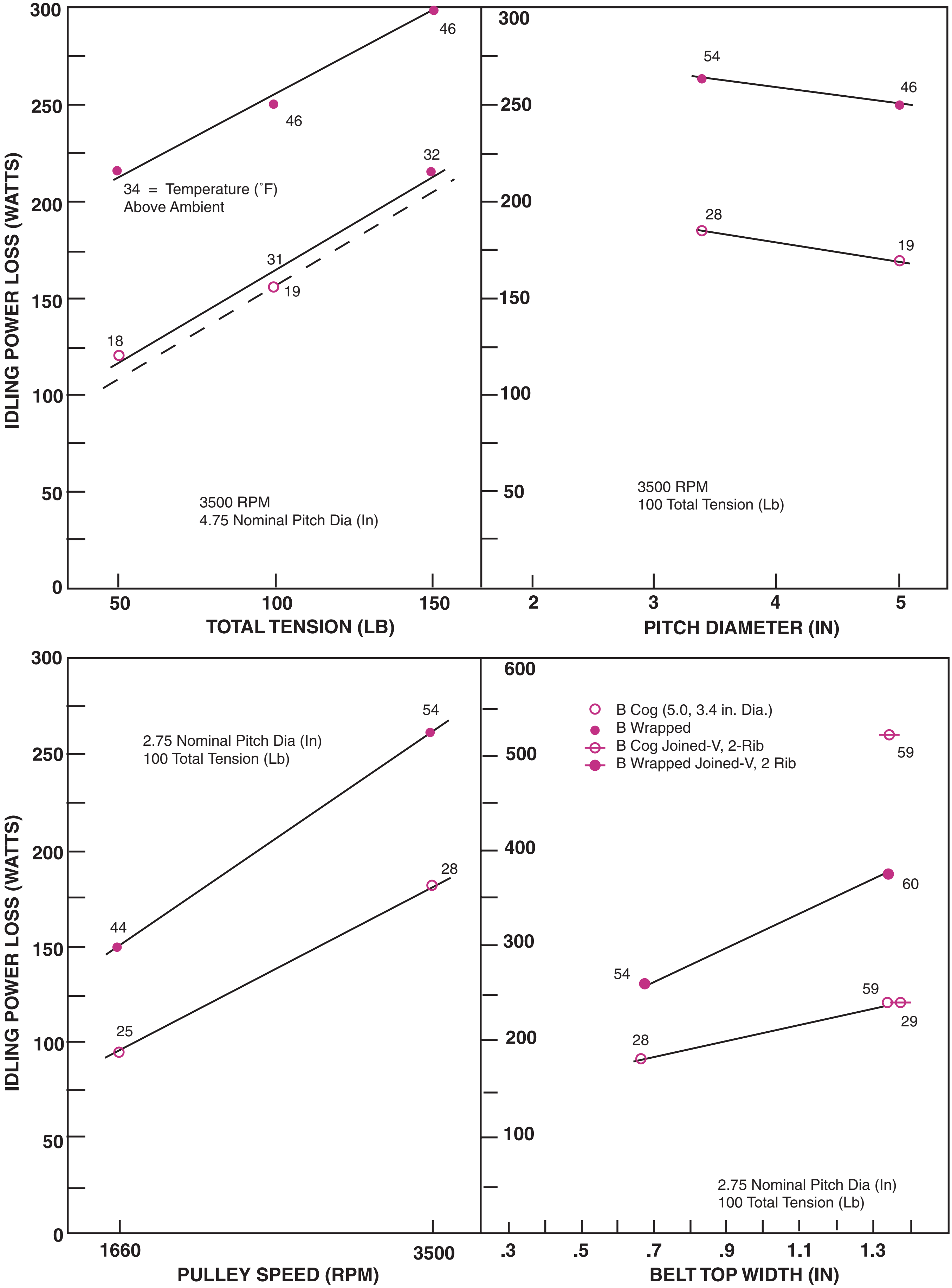


Fig. 3 Idling Power Loss Dependence on Tension, Diameter, Speed and Width

Table 2 Industrial Belt Efficiency at Rated Power

Belt Cross Section	Percent Efficiency		Horsepower Loss		Percent Slip		Temp Above Ambient (ºF)		DR and DN Pitch Dia (In)	Rated Torque (Lb-Ft)	Total Tension (Lbs)	Nominal RPM	No. of Tests
	Wrap	Cog	Wrap	Cog	Wrap	Cog	Wrap	Cog					
Classical-V													
A	91.4	93.4	.17	.13	1.26	1.03	33	21	3.0	5.5 P^	66	1750	32
A	90.6	93.2	.25	.17	1.31	.98	39	22		7.1 C	85		16
2A	90.7	93.3	.38	.27	1.34	1.	48	28		11.0 P	132		16
A	97.3	97.7	0.16	0.14	0.67	0.4	15	9	6.2	16.7 P	97		8
A	96.9	97.5	.23	.18	.77	.56	22	12		21.2 C	123		8
B	90.8	95.6	.12	.11	1.34	.79	23	14	3.4	3.9 S	42	1750	38
B	90.1	95.1	.19	.09	1.54	1.06	29	18		5.4 P	57		100
B	92.1	95.3	.32	.19	2.31	1.40	45	27		11.4 C	121		14
2B	89.7	95.7	.30	.12	1.48	.71	29	19		7.8 S	84		12
B Joined-V*	86.2	94.4	.40	.15	1.48	.78	39	18		7.8 S	84		6
B	94.7	96.3	.24	.17	1.28	1.07	26	18	5.0	13.2 S	93	1750	13
B	95.7	96.8	.23	.18	1.45	1.17	28	21		15.7 P	113		36
B	95.9	96.5	.31	.28	1.79	1.40	39	32		21.6 C	156		13
B	96.9	97.5	.23	.18	.85	.64	24	20	6.6	21.1 S	115	1750	10
B	96.9	97.5	.26	.21	.96	.71	29	23		25.0 P	136		10
B	96.9	97.6	.33	.25	1.14	.83	33	28		30.9 C	169		10
C	97.4	99.6	.41	.08	2.04	1.38	42	22	8.0	68.3 C	308	1160	16
2C	97.4	99.3	.58	.16	1.48	1.06	37	20		100.5 P	452		8
5C	97.4	98.9	1.49	.63	1.45	1.01	54	27		251.2 P	1130		16
5C	96.9	98.8	2.37	.99	1.91	1.13	78	38		341.7 C	1538		8
C Joined-V**	97.5	98.5	1.42	.85	1.13	1.17	58	38		251.2 P	1130		8
D	96.9	97.4	.80	.70	.89	.53	37	27	12.0	113.6 P	341	1160	8
4D	96.8	97.5	3.35	2.55	.83	.55	62	45		454.4 P	1364		8
Synchronous													
L075		97.0		.05		.00		5	3.342	5.0	50	1750	24
L038		98.2		.04		.00		8	4.775	7.2	50		8
L075		98.1		.05		.00		6		7.2	50		16
L075		97.3		.07		.00		9		7.2	80		15
XH400		99.4		.42		.00		25	8.356	272.2	1040	1750	8

^ S, P, and C denote standard, premium, and cog ratings; 1972 Dayco PT Handbook.

* 2-rib wrapped, 2-rib cog.
** 5-rib wrapped, 4-rib cog.

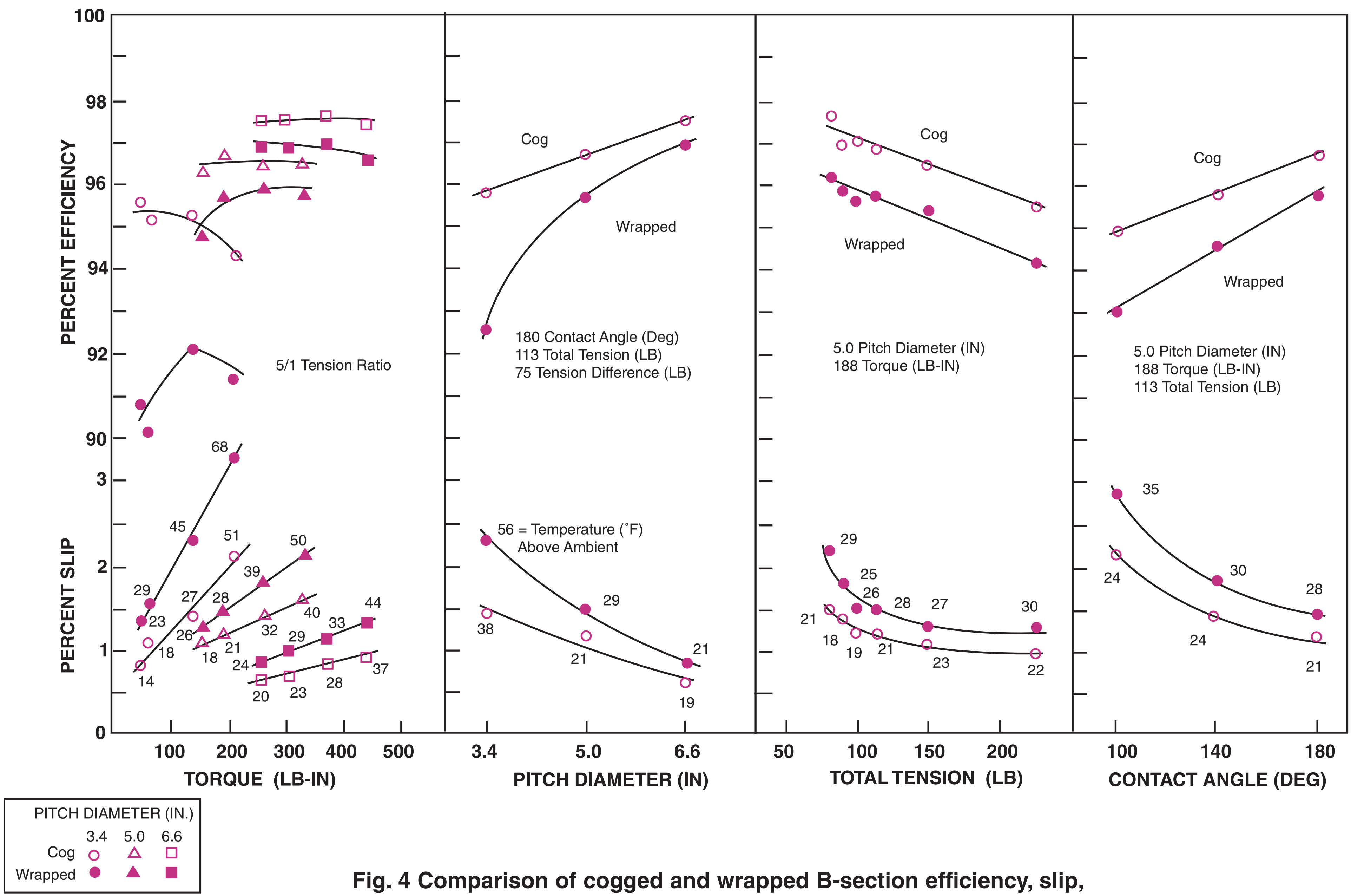


Fig. 4 Comparison of cogged and wrapped B-section efficiency, slip, and temperature at torque, diameter, tension, and contact angle variations about 1750 RPM, 5 In. rated power

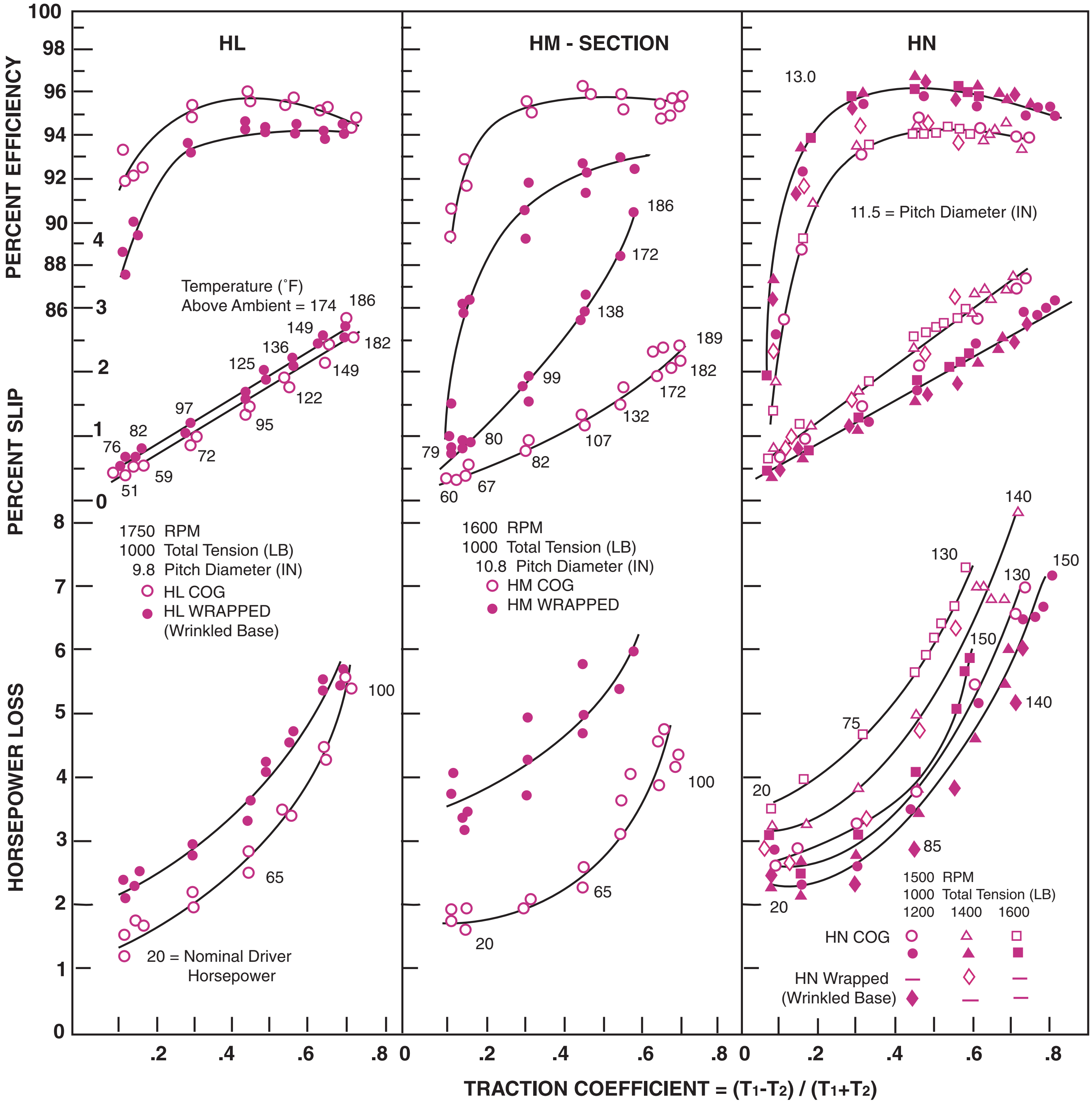


Fig.6 Agricultural variable speed belt efficiency, slip, temperature, and power loss

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