EFFICIENCY COMPARISON OF MODERN VARIABLE SPEED DRIVE TECHNOLOGIES

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Abstract: Brushless D.C. technology is new to the general industrial maketplace and is one of the new technology variable speed drives. Efficiency and performance comparisons will be made between the various technologies available to assist the end user in choosing a technology appropriate to the job to be done. Basic theory will be presented for Brush type DC, AC induction, AC vector, and Brushless DC types and actual results of independent tests will be presented to support the conclusions.

I. Types of Modern Drives

A. AC Induction
B. Brush DC
C. AC Vector
D. Brushless DC

II. Basic Theory of Operation of Drive Types

III. Areas of performance comparison

A. Speed/velocity accuracy
B. Dynamic Response
C. Power Factor
D. Line Harmonics
E. Efficiency

IV. Actual Independent Testing Comparisons

A. Punch Press - Constant Speed AC motor vs Brushless DC retrofit of existing machine.
B. General test - Brush type DC vs Brushless DC

V. Conclusions and Summary

A. Brushless DC has advantage in all areas of performance over fixed speed AC.
B. Brushless DC has advantage in all areas of performance over Brush DC.

I. Introduction: Variable Speed drive techology has made significant advances in the last 10 years primarily due to the recent availability of both high power switching devices and magnet materials that were not available in earlier years. Technology has been known for 30 years or more to design such equipment but the parts have not been available to make them reliable at competitve prices. A description of basic drive types is presented below together with a summary of the efficiency parameters typical of each type. The specific types referred to are:

AC Induction with PWM VVI Controller
AC Induction with Vector Controller
Brushless DC
Brush DC (as a baseline for comparison)

II. AC Induction: The AC induction motor was invented by Nikola Tesla in 1924 and became the most commonly used motor type and remains so today. It has the characteristic that motor shaft speed is proportional to the applied frequency and inversely proportional to the number of poles. The induction principle requires that the motor rotor (squirrel cage) develop flux induced from the stator current. This requires that a "slip" occur between the rotating flux of the stator (3600 rpm at 60 hz) and the actual turning speed of the motor shaft (3500 rpm typical for 2 pole motor). Once the rotor flux is established through slip, the flux fields from the stator and rotor interact to produce torque output. The AC motor has the advantage of being stone simple and widely available. Two types of modern drives (there are some variations but they are not widely used) utilize this motor design. They are the PWM type AC Inverter and the newer Vector Inverter.

The PWM type Inverter produces three phase sinusoidal current output at frequencies adjustable typically over a range of 3 to 120 hz holding the motor voltage at a constant ratio relative to frequency. This ratio is relatively fixed but it is necessary to increase it at low speeds to correct for the low speed losses and it is typically necessary to let it decrease at speeds above the 60 hz level. This type of controller on an AC motor is open loop. That is, the controller commands the motor to run at a speed but if load causes a change in speed, there is no actual feedback device used to detect and correct the speed change that occurs. While this simple type of controller is acceptable for some applications, it cannot replace high accuracy, high dynamic response requirements usually performed by brush type DC drives.

The Vector controller is similar to the AC PWM variable frequency controller from a power point of view, but works on a completely different control principle. In the vector controller, the flux in the rotor is produced dynamically by the instantaneous current in the stator, as controlled by the solution of an algorithm (formula) that results in the vector current necessary. Vector refers to the amount and the angular direction of the current. This vector changes both in amount and angle dynamically as the motor changes either speed or load, or both and the change can be very quick. Consequently the algorithm; which is based on current, temperature, voltage, speed, and motor inductance and resistance must be continuously calculated fast enough to control the motor parameters. Using this technique, assuming it is properly designed and uses an encoder or other precision feedback device on the motor shaft, provides very good accuracy and dynamic response from a relatively ordinary AC Induction motor. It does not however improve the efficiency of the motor at rated speed and load conditions.

III. Brushless DC Drives

The Brushless DC motor works on a principle like that of the brush DC machine, hence the name. One can think of it as an inside out DC motor in which the field windings are replaced with permanent magnets and moved from the frame to the shaft. The armature still consists of multiple windings and are moved from the shaft to the frame. In effect the "fields" now rotate and the"armature" stays still. Because of the obvious mechanical similarity to the AC motor, however, the parts are referred to as Stator and Rotor. The power section of the controller is nearly identical to the Vector Inverter and uses a PWM method of current control but the similarity stops there. The current is not controlled sinusoidally, but trapezoidly. Current is also only conducted in two of the three motor wires at a time instead of being conducted in all three of the wires at a time vectorially. Brushless DC is very simple compared to a Vector Drive since it only switches DC to a pair of wires at a time and determines which wires to switch on based on an encoder made inside the motor. This encoder is essentially the "commutator" and is a very simple magnetic device with magnetic sensing switches rather than being an optical device as is typically the case with normal encoders.

Comparisons of efficiency

Actual data was taken in a test commissioned by the Ontairo Hydro power company in Canada to determine the comparison of a conventional brush type drive and a Brushless DC type drive for the purpose of determining whether rebates for power savings would be appropriate using the newer technology drive and whether the claims being made by the manufacturer were substantiated by independent testing. The equipment used was a POWERTEC Brushless DC system with a 25 hp Totally Enclosed Non-Ventilated motor (TENV) which was rated for 100:1 speed range at full rated torque and did not require a cooling fan. The brush DC system was an Emerson controller and Leroy-Sommer 20 hp Blower Cooled motor with a 20:1 full torque speed range. The equipment was tested by Ortech International Energy Technologies and a detailed report was prepared for Ontario Hydro (1). The specific characteristics tested were: Efficiency, Power Factor, Accuracy, and input line harmonics. No representatives from the manufacturers of the drives were allowed to be present during the testing. The following data are taken from this report.

Tables 1 through 3 show the efficiency of the two systems at variable speeds from 10% to 100% and variable loads from 25% to 100%. The results show Brushless DC efficiency increases over brush type of 13% at full speed and load to 206% at 10% speed, 25% load. Note that there is difference in the rated HP of each system but each system was run to percentages of it's full load rating.

BRUSHLESS DC DRIVE, POWERTEC - 25 HP
EFFICIENCY IN PERCENT, AC LINE TO OUTPUT SHAFT
TORQUE, PERCENT OF RATED

%RPM	100%	75%	50%	25%
100	87.9	86.7	85.0	78.4
75	85.4	84.9	82.9	76.6
50	80.8	80.0	79.0	72.6
25	69.8	67.6	66.8	64.3
10	65.1	65.1	65.1	58.9

TABLE 1

BRUSH DC DRIVE, EMERSON - 20 HP
EFFICIENCY IN PERCENT, AC LINE TO OUTPUT SHAFT
TORQUE, PERCENT OF RATED

%RPM	100%	75%	50%	25%
100	77.8	77.1	76.6	N.A.
75	74.0	72.6	68.7	65.4
50	66.7	65.1	60.9	50.9

25	51.8	50.4	46.7	38.1
10	31.3	30.0	26.9	19.2

TABLE 2

INCREASED PERCENTAGE EFFICIENCY
OF BRUSHLESS OVER BRUSH TYPE DRIVE
TORQUE, PERCENT OF RATED

%RPM	100%	75%	50%	25%
100	13.0	14.0	15.5	N.A.
75	15.4	16.6	22.1	17.1
50	21.1	22.8	29.7	42.6
25	34.7	34.1	43.0	78.1
10	108.0	117.0	142.0	206.7

TABLE 3

Tables 4, 5 and 6 present similar data but for Power Factor rather than efficiency. Power factor is a relative measure of how much of the input current is being used to produce useful work versus how much is reactive. The results show significantly higher power factor near base speed for the Brushless DC drive and at low speeds the Brushless DC drive is well over 200% better than the brush drive.

BRUSHLESS DC DRIVE, POWERTEC - 20 HP
MEASURED AC INPUT POWER FACTOR
TORQUE (PERCENT OF RATED)

%RPM	100%	75%	50%	25%
100	.93	.95	.94	.90
75	.95	.95	.94	.87
50	.95	.95	.91	.81
25	.94	.92	.85	.72
10	.83	.80	.77	.72

TABLE 4

BRUSH DC DRIVE, EMERSON - 20 HP
MEASURED AC INPUT POWER FACTOR
TORQUE (PERCENT OF RATED)

%RPM	100%	75%	50%	25%
100	.80	.81	.81	NA
75	.65	.64	.63	.62
50	.48	.48	.47	.46
25	.32	.32	.32	.33
10	.22	.22	.22	.26

TABLE 5

INCREASED PERCENTAGE POWER FACTOR OF BRUSHLESS OVER BRUSH TYPE DRIVE
TORQUE (PERCENT OF RATED)

%RPM	100%	75%	50%	25%
100	16.0	17.2	16.0	NA
75	46.1	48.4	49.2	40
50	100.0	98.0	93.6	76.0
25	193.8	187.5	165.6	118.2
10	277.3	263.6	250.0	176.9

TABLE 6

AC input harmonics were also measured in the same series of tests and harmonics up to the 30th were measured at full speed and half speed at full load. The reader should refer to the complete report if all the harmonic results are desired but full load, full speed results are shown below out to the 13th harmonic. Other speeds and loads show similar results.

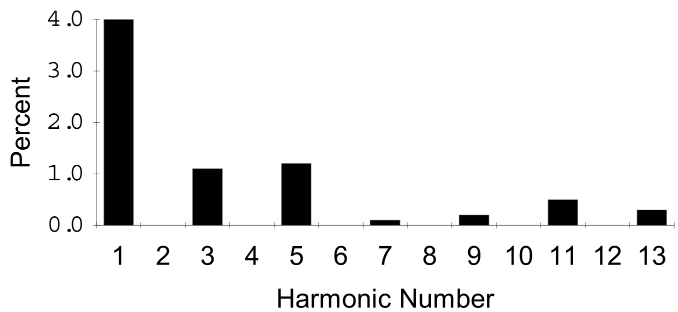

Chart 1: POWERTEC Harmonic Results

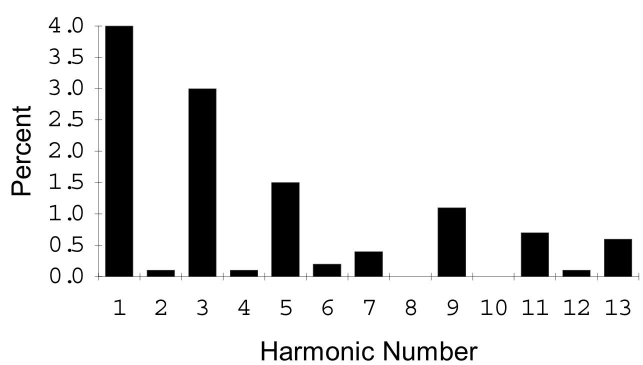

Chart 2: Brush DC Drive Harmonic Results

The data show that the 3rd, 5th, 7th, and 9th harmonics which are usually highest and cause the most concern were markedly lower for the Brushless system. Note that the fundamental (1st harmonic) is truncated on both graphs for readability and they are really both 100%, not 4% as shown on the axis.

Summary and Conclusions

Based on these data it is obvious that Brushless D.C. demonstrates significant advantages over the conventional brush type technology using the SCR type controller. While there is a more complex controller used with Brushless D.C., it is no more complex than modern variable frequency type drives and the motor is very simple with no wear out parts except bearings. These data show increased efficiency, more accurate speed control, higher power factor, and lower line harmonics than conventional DC drive technology.