TRAK ®**MACHINE TOOLS**

SOUTHWESTERN INDUSTRIES, INC.

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White Paper

# Variable Frequency Drives – Some Basic Information

Purpose

This document will explain what a Variable Frequency or Inverter drive (VFD) is and why we use them in our products.

SWI include a Variable Frequency or Inverter drives to electronically control the spindle rpm in our VM, VL, SMX, and SLX line of controls.

Variable frequency drives allows us to control the speed of an alternating current (AC) induction motor electronically. A traditional application for an induction motor in a machine shop would be a bench grinder. Note that when the motor is turned on it runs at a no load speed of approximately 1800 rpm as stated on the motor nameplate. The reason for this is that the motor is supplied by a constant 60 Hz AC voltage.

Background Information

60 Hz refers to the rate at which the AC voltage alternates between positive and negative voltage. The following diagram is a picture of what AC voltage looks like on a typical single phase 120 volt line.
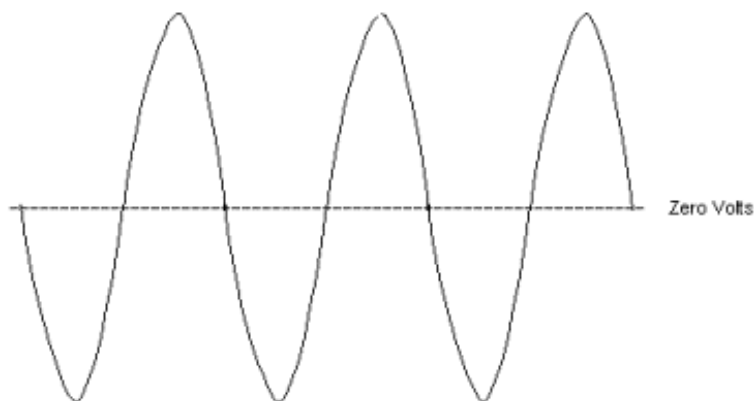
Specifically Hz means the number of cycles per second or cycles/sec. 60 Hz means that the voltage cycles 60 times per second, additionally one cycle is defined as 360 degrees. One cycle for our discussion means going from zero volts to negative volts to zero volts to positive volts and back to zero.

Note: A three-phase 220 volt line contains three sine waves, 120 degrees apart.

As stated earlier the no load rpm of an induction motor is 1800 rpm. Due to the design of the motor it is the frequency not the voltage of the supplied AC voltage that determines the speed of an induction motor (the reason for this is beyond the scope of this document). Therefore if we change the frequency of the supply AC voltage we can change the no load speed of the motor. For example the following table lists AC voltage frequency and motor rpm.

| Frequency	Motor Speed
60 Hz	1800 rpm
30 Hz	900 rpm
120 Hz	3600 rpm

Different Types of Varispeed Drives

The three common types of varispeed drives are:

1) Variable Frequency Drive
2) Vector Drive
3) Sensorless Vector Drive

A Variable Frequency drive is the simplest and least expensive of the three types. It takes:

1) the AC supply voltage that the drive is connected to and
2) manipulates the frequency electronically to
3) allow the user to change the frequency, from 0-200 Hz, of the voltage the drive supplies to
4) the motor connected to the drive.

The following diagram shows this pictorally.

     (1)   (2)   (3)   (4)

(60 Hz VAC) → Variable Frequency Drive → (0 to 200 Hz VAC) → Induction Motor
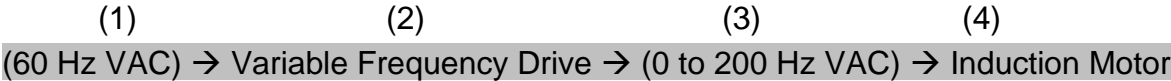
Note: The Variable Frequency drive converts the input AC voltage to DC (direct current) voltage and then "Inverts", hence the name "Inverter Drive", the DC voltage back to AC voltage with variable frequency.

A Vector drive is the most complex and most expensive of the three types. It essentially converts an AC induction motor into a brushless servo motor.

The Vector drive not only varies the frequency of the AC voltage but also manipulate the electro magnetic field in the induction motor to maintain torque throughout the entire rpm range motor and down to near zero (0) rpm (the details of this is beyond the scope of this document). This is accomplished by mounting an encoder on the non-business end of the output shaft of the induction motor.

Note: The term "Vector" is a mathematical expression that refers to the magnitude (or how much) and direction of, in this case, a magnetic force. Hence the name Vector

Drive means a drive that can control the magnitude and direction of the magnetic force in an AC Induction motor.

The sensorless Vector drive is an enhancement of a variable frequency drive. It combines the low cost of a variable frequency drive with almost identical torque characteristics of the Vector drive. The sensorless Vector drive does not require an encoder, instead it is able to calculate the position of the output shaft based on the drives output current and voltage.

An added bonus of both the Vector and Sensorless Vector drives are that they can provide up to a 150% increase in torque or what you may call peak torque. Peak torque is defined as the torque that the motor can provide for a very short time period (typically less than a minute). Continuous torque can be maintained for long periods of time.

The following table gives the peak and continuous torque achieved at the motor's output shaft for a 3hp A/C Induction motor with and without a sensorless Vector drive. The torque can be solved using the following equation:

$$hp=(torque*rpm)/63025$$

or

$$torque=(hp*63025)/rpm$$

No Vector drive, 3 Hp Induction motor **continuous torque**	**No Vector drive**, 3 Hp Induction motor **peak torque**	**Sensorless Vector drive**, 3 Hp Induction motor **continuous torque**	**Sensorless Vector drive**, 3 Hp Induction motor **peak torque**
105 in-lbs	105 in-lbs	105 in-lbs	105*1.5 =158 in-lbs

Note: It is important to know which rating, peak or continuous, is advertised when comparing horsepower between two machine tools.

From the above table it can be seen that without a Sensorless Vector drive if we solve for Hp at the motor's shaft we get:

$$Hp=(105*1800)/63025$$

$$Hp=3$$

However if we use peak torque based on using a Sensorless Vector drive on the same AC Induction motor and solve for Hp at the motor's shaft we get:

$$Hp=(158*1800)/63025$$

$$Hp=4.5$$

From the above example it should be clear that when stating Hp, the details of how the rating was obtained needs to be clarified. SWI uses the Hp stated on the motors name plate which is a continuous rating.

SWI currently uses the sensorless Vector drive type manufactured by Yaskawa. Yaskawa is a leading Japanese manufacturer of automation equipment that has been in business since 1915 with offices throughout the world.

Spindle Control vs Non-Spindle Control

The non-spindle control head uses a traditional hi/low back gear, mechanically adjustable gear ratio spindle (hand crank on side of head) while the spindle control uses an electronically variable, fixed gear ratio spindle (sensorless vector drive). Both designs have distinct advantages.

The non-spindle control head's advantages are:
1) Very high torque output at the spindle in low back gear and mid to low rpm speed range (70 – 250 rpm) due to high gear ratio between the motor and the spindle. This results in an increase in torque at the spindle.

2) Manual quill control.

The spindle control head's advantages are:
1) Constant torque from the minimum rpm of the machine to the base speed of the motor (60 Hz or 1800 rpm). The ratio between the motor and spindle determines the rpm at which constant torque applies to the spindle.

2) Infinitely variable speed control that can be set and modified in the control as well as stored with the program.

3) Ability to maintain set rpm under varying tool loading.

4) Lower maintenance due to lower mechanical parts count.

5) Electronic spindle braking.

The non-spindle control head is able to produce very high torque output at the spindle because of the large gear ratio between the Induction motor and the spindle. The high gear ratio mechanically increases the torque of the motor by the amount of the gear ratio. For example the spindle control head in low gear and at the slowest setting of 70 rpm is approximately a 25:1 gear ratio. This can be calculated by knowing the diameters of the pulleys and the gears or by knowing the rpm of the motor and the rpm of the spindle. From the motor nameplate the no load speed of the motor is 1800 rpm. From the nameplate on the front of the head of the mill the low gear slowest rpm is 70. Therefore:

$$\text{motor rpm} = \text{spindle rpm} * \text{gear ratio}$$
$$\text{gear ratio} = \text{motor rpm}/\text{spindle rpm}$$
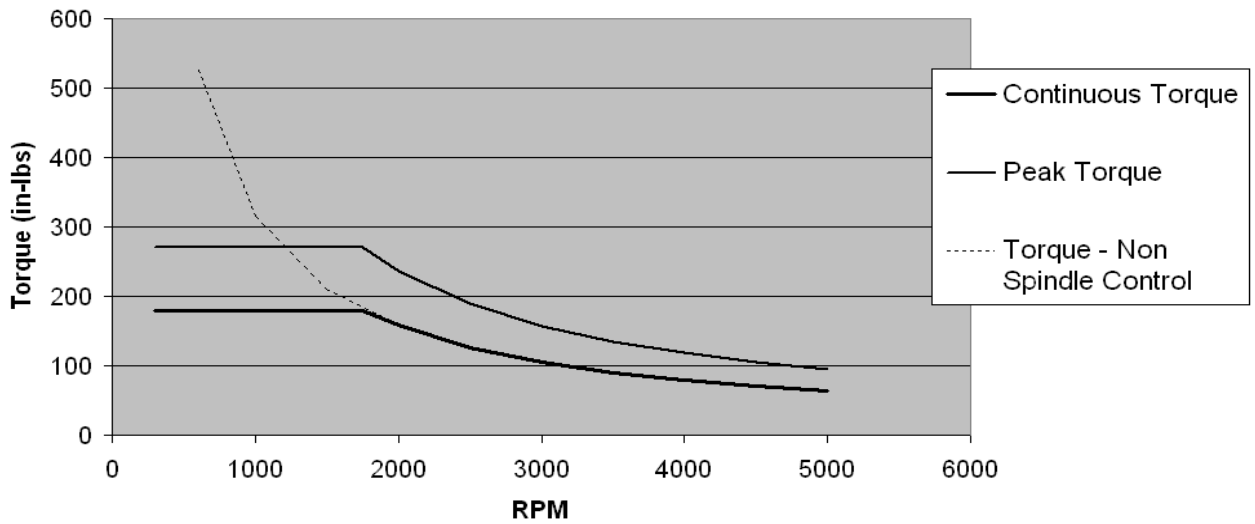$$\text{gear ratio} = 1800/70$$

gear ratio~25

The following charts illustrate the torque vs. rpm curves for a spindle control and non-spindle DPMSX3, DPMSX5, and K4 in both high and low
gear.

DPMSX3, DPMSX5, K4 Torque vs RPM at Spindle - Low Gear
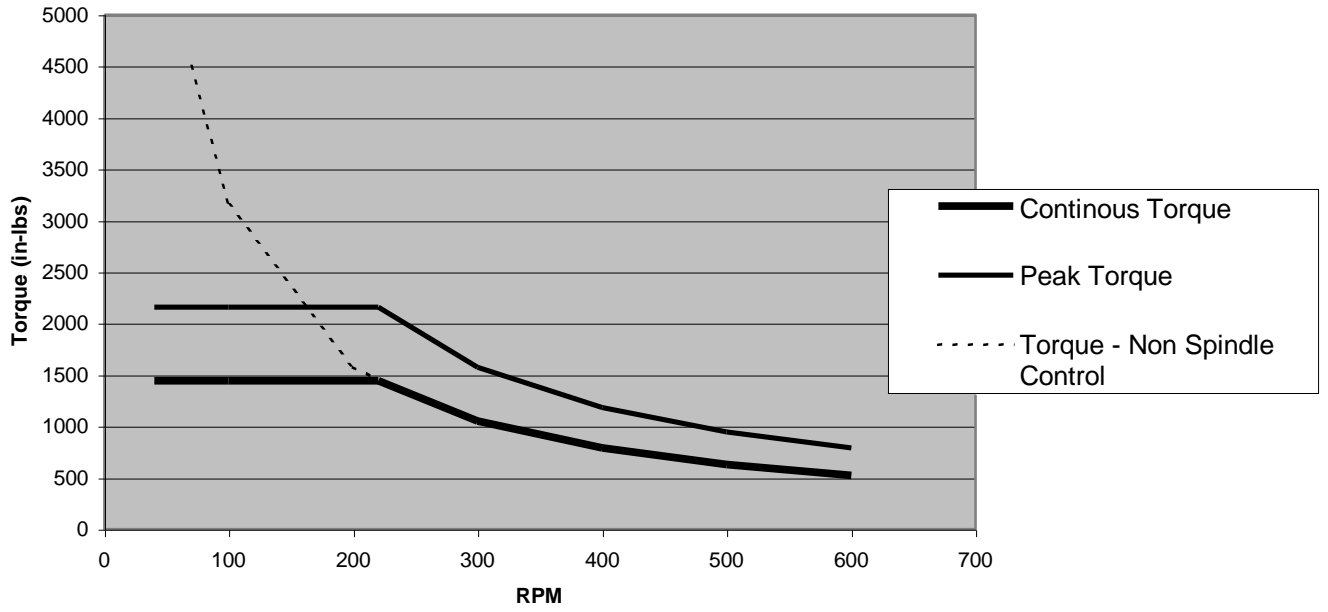
DPMSX3, DPMSX5, K4 Torque vs RPM at Spindle - High Gear

The following data were used to create the charts on the previous page.

DPMSX3, DPMSX5, K4 Torque vs RPM Curves - Spindle Control and non Spindle Control Machines

HP = (Torque x RPM)/63025 Torque values in in-lbs

Non Spindle Control Head

The following torques were calculated for machines that have a 5 HP spindle motor.

Torque (in-lbs) is calculated at the spindle

High Gear   **Low Gear**

Ratio from motor to spindle varies

RPM	Torque	Ratio	RPM	Torque	Ratio
600	526	2.92 to 1	70	4500	25 to 1
1000	315	1.75 to 1	100	3150	17.5 to 1
1500	211	1.17 to 1	200	1575	8.75 to 1
2000	158	0.875 to 1	300	1049	5.83 to 1
2500	126	0.7 to 1	400	788	4.38 to 1
3000	105	0.58 to 1	500	630	3.5 to 1
3500	90	0.5 to 1			
3950	79	0.44 to 1			

Spindle Control Head

Continuous Torque - the maximum torque the spindle motor can provide on a continuous basis.
Peak Torque - the peak torque the spindle motor/AC drive combination can sustain for 1 minute or so.
This value is typically 150% of the continuous torque.

Torque is constant from 300 RPM to 1750 spindle RPM in high gear.
Torque is constant from 40 RPM to 220 spindle RPM in low gear.

High Gear - 1 to 1   **Low Gear - 8 to 1**

RPM	Continuous Torque	Peak Torque	RPM	Continuous Torque	Peak Torque
300	180	270	40	1440	2160
1000	180	270	100	1440	2160
1750	180	270	220	1440	2160
2000	158	237	300	1050	1575
2500	126	189	400	788	1182
3000	105	157.5	500	630	945
3500	90	135	600	525	787.5
4000	79	118.5			
4500	70	105			
5000	63	94.5			