Purchase guide for VMC

Introduction

This document was written by ***Victor Taichung Machinery*** to provide our customers with information to understand why the pricing of Vertical Machining Centers (VMC) can differ so much among various machine tool builders. Most issues are concentrated on the C-frame VMC with fixed column and applied to the existing models of the Victor Vcenters-55/70/85/102/110/130/145.

Travel for 3 axes

Axis travel is one of the primary specifications the customers will consider when purchasing a Vertical Machining Center (VMC). It is very easy for customers to compare the specification tables in the product brochures. However, a frequently overlooked factor that influences the machine performance and service life is the ***machine rigidity or stiffness.*** It is difficult to extract this information from the pictures or specification tables within a brochure.

The picture at the right illustrates how dimensions D, H and W affect stiffness, deflection or deformation.

$$Stiffness \sim \frac{H^3 \sim W^3}{D^3}$$

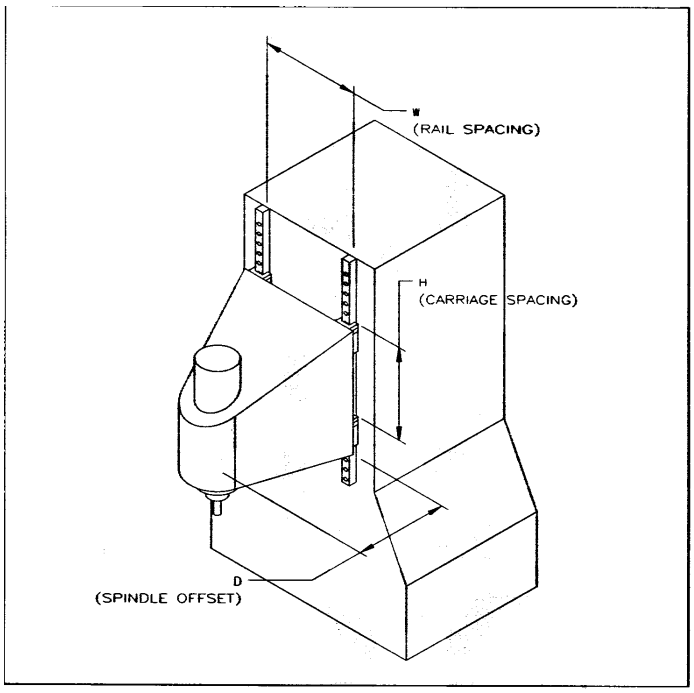


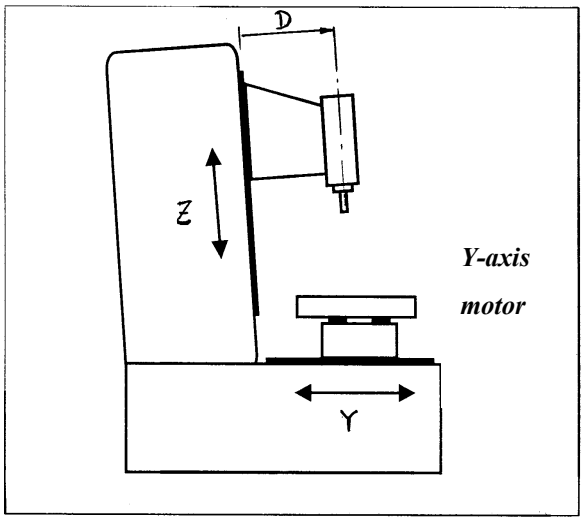
Figure 2-11:
The spindle-slide-column assembly of a vertical machining center must be constructed so as to provide adequate way spacing relative to Y-axis throat (*D*). Stiffness drops rapidly with increasing *D* and decreasing *H* and *W*.

The ***width of the linear guides or box slideways*** also determines the load capacity of each axis. Box slideways carry larger loads than linear guides. In addition, there are other design considerations for each axis. If the above factor is modified, the stiffness can be improved; however, the machine will have to be a larger design and will create increased weight, cost and selling price.

(1) **Y-axis:** The Y-axis travel is most important. It is related to (D) ***maximum spindle offset*** (the distance from spindle center to column) and ***overhang deflection*** (the gravity of the table at the end of X-axis travel).

(a) Spindle offset:

If the spindle-offset (D) is over-extended, an increase in physical mass of the headstock is necessary to compensate for the reduction in rigidity. However, there are physical limitations to this extended offset. To support the larger headstock, the C-frame VMC would become so large that the customer would find the bridge style machine a better choice for the required work envelope.

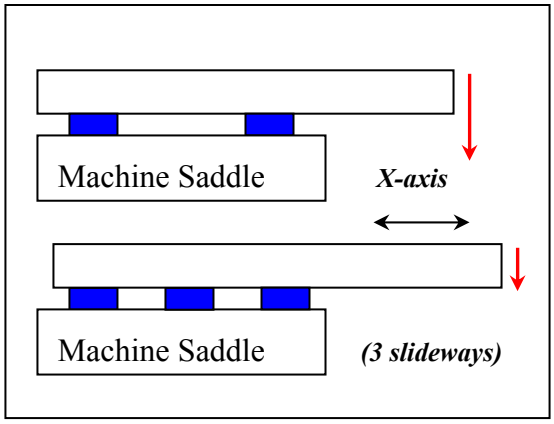


(b) Front-mounted Y-axis motor for greater rigidity:

The design advantage of a front-mounted Y-axis servo-motor is to shorten the ball screw length which increases the rigidity and positioning accuracy of the carriage. One disadvantage of a front-mounted Y-axis motor is ergonomic…the machine operator will find it difficult to gain easy access to the spindle. The VICTOR (FORTUNE) Vcenters with Y-axis travel less or equal to 600mm (Vcenter 55/ 70/ 85/102/110/130) utilizes the front mount design and ergonomic. Only the Vcenter-145, with 700mm Y-axis, is designed with the servo-motor in the rear of the machine base.

(c) Deflection due to the table weight at the end of X-axis travel:

As table deflection is inevitable at the end of the X-axis travel, the best solution is to reduce the overhang by increasing the number of slideways on the Y-axis. The Vcenter-110 and Vcenter-130 have **3** linear guides in the Y-axis and **4** box slideways for Vcenter-145.



VICTOR Vcenter-110/130
with 3 linear guides in Y axis

(2) X-axis:

The numbers of blocks (nuts) installed on each linear guide to support the table weight is the key factor. Victor Taichung's design is to always install 3 blocks in X-axis to support the long table, however, many competitors install only 2 blocks to save the cost and thus lower the price.

(3) Z axis:

As mentioned previously, the carriage spacing (H) and spindle-offset (D) are very important for the structure stiffness. The customer can easily identify if the headstock is strong enough by the picture of the headstock in the catalog. Another factor is the maximum travel for the Z-axis. It is very important when installing a rotary table (4th axis) or hydraulic fixture. Victor's design is strong enough to increase the column length by adding a riser block between the column base and machine bed. However, *this increase on the column height will affect the sea freight cost* because the machine has be to delivered by the open flat rack rather by the standard container. Victor's design philosophy has considered to maximize the Z axis travel so that the machine can be packed and shipped by the standard HQ container to lower the pricing for the customers.

(4) Along with the 3 axis travels being important, so is the diameter of the ball screws. The ball screws are installed to move heavy loads on the headstock, table and workpieces on the worktable.

The following photos are abstracted from the brochure of Hartford and Feeler, two VMC machine uilders in Taiwan. In comparison with the headstock and machine structure, Victor Vcenter's series VMC definitely cost more with much better structure rigidity for heavy cutting and even longer service life for the Vcenter machines.

Hardford VMC-1020 S/A

Feeler FV-1000

VICTOR Vcenter-110/130

Rapid feedrate

The higher value for the axis rapid feed does NOT guarantee the machine ranking or quality. There are three factors to determine the rapid feed rate:

(1) Box slideways or Linear guides:

The box slideways with heat treatment can withstand the heavy loads on the contact surface and is preferred for heavy cutting of carbon ferrous and stainless steel. However, there exists feed rate limitation of 24 m/min for box slide-ways because of the flat surface contact. (Machine builders using box ways are required to employ highly skilled technicians to scrape the gib to adjust the clearance between contact surfaces so the overall labor cost is higher.) On the other hand, the linear guides, with smaller contact surfaces, are attached to the casting with bolts and the assembly is much easier and requires a less skilled workforce. The rapid feed rate is increased, loading capacity is lower, price is cheaper and structure rigidity is reduced.

(2) Pitch of the ball screw

The pitch of the ball screw means the traveling distance for every rotation of the ball screw. Increasing the pitch can easily make the feed rate quicker but sacrifice the positioning proportionally. Carefully review the pitch value for each axis ball screw.

(3) Servo motor (feed motor)

The rpm of the servo motor is another factor that increases the rapid feed rate. The feed rate can be upgraded by either using a more expensive, higher rpm motor, or modification to the ball screw pitch. The responsible machine tool builder would specify the higher speed motor and meet the positioning accuracy first, then design the optimal pitch for the ball screw.

Meehanite Cast iron or Weldments

Not all machine tool builders use Meehanite cast iron for their machines. Weldments, consisting of steel plate welded together, and often filled with sand, shot, and sometimes polymer concrete, have been used in machine tool structure for many years. Tooling costs associated with weldments are low compared to the cost for cast iron patterns or polymer concrete molds. The weldment designs are far less expensive for very low-volume machine tool producer.

Weldments, particularly when unfilled, possess several drawbacks relative to cast iron. First, the structure is non-uniform in its properties, and very hard to model and optimize due to the presence of weld seams. Because it is fabricated from steel plate, damping is exceptionally low in unfilled weldments. The cost to fabricate weldments is also very high, and machinability is lower than that of cast iron. The change in shape of a weldment when subjected to varying thermal conditions is difficult to predict, and typically, less uniform than homogeneous structures made of cast iron or polymer concrete. This can lead to bending and twisting under thermal loads, greatly distorting machine geometry.

The strength of welded structures under constant loads approximates the strength of the plate and weld materials. In the case of butt welds, the weld material, if not ground off, provides static reinforcement, but under dynamic loading, the weld serves as a stress concentrator, reducing overall fatigue strength. Similarly, fillet welds act as stress concentrators, reducing the effective load bearing capacity of a welded structure under dynamic loads. ***The fact that welds can act as stress concentrators detracts from their suitability for high performance machine tools.***

Meehanite® Cast iron

Even though most machine tool builders claim they use Meehanite® cast iron for their machines, but there still exist some difference on the cast irons.

Grey cast iron, which is used for most machine tool castings, is available in wide array of grades from class 20 to class 60. The class represents the minimum tensile strength of the material in pounds per square inch (psi). Grey irons in class 20 through 35 are characterized by excellent machinability , high damping low modulus of elasticity (akin to stiffness) and are easier to form into castings. Class 40 through 60 gray irons, on the other hand, have less damping, higher stiffness and are more difficult to pour into casting and machine.

Because most of the damping provided by a machine tool is not directly a function of the damping properties of the structural materials themselves, it is highly recommended that the consumers should seek at least ***class 40*** (and preferably class 50) cast iron, depending on the size of machine and the structure role of the casting in question. *Class 50 iron castings are more expensive to manufacture and machine, but the benefits in stiffness are well worth the additional cost.*

The following formula for the deflection (δ) of one beam under the tensile loading (F) can be useful to have more understanding on the important of cast iron grades:

$$\delta axial = FL/AE$$

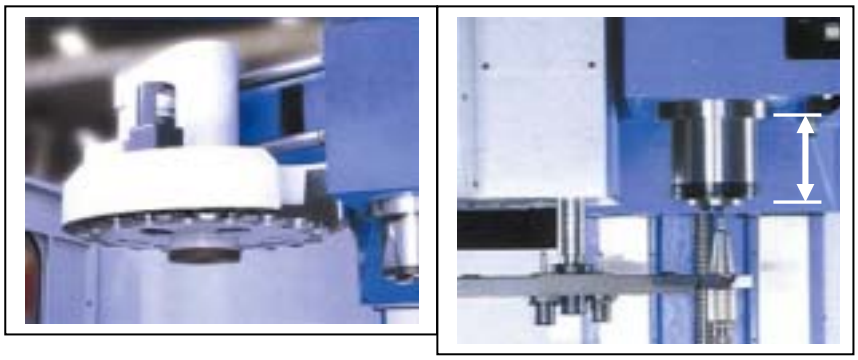
where L is the length of the beam , A is the cross-sectional area and E is the elastic modulus. For class 25 iron, E_class_25 is $12x10^6$ and E_class_50 is $18x10^6$ psi. Therefore, *δ_class_50 is* ***33% less*** *than δ_class_25 in the deflection* under the same cutting loading and thus affects the accuracy.
Victor's has her own foundry (certificated by Meehanite® organization) to offer flake-graphite gray cast iron to meet the so-called Meechanite® specification GM-60 and GA-50 which offer optimal damping and reduce the deflection under machining loading in comparison with lower grade casting suppliers without Meehanite® certification. (GM-60 & GA-50 is equivalent to GM-400 & GA-350 for Japanese JIS specification.)

ATC type and tool magazine

The most popular Automatic Tool Changer (ATC) available on VMC's are "ram type" and "umbrella" type. The ram type (or "arm type") uses one rotating arm mechanism to exchange the tools and is very fast. The slower umbrella type exchanges the tool with a hydraulic device between magazine and spindle. Victor Taichung's engineering design uses the more expensive "ram type" exclusively to improve reliability and deliver a faster tool change cycle time.

The spindle has to extrude the headstock for the umbrella type and cause the spindle stiffness weaker. Victor has never installed umbrella type in the past because this design will have to sacrifice the spindle rigidity under the compatibility for the arm type and umbrella type ATC.

The following photos are abstracted from the brochure of Supermax. The spindle extrudes much longer from the headstock than Victor's Vcenter design because of the compatibility for these two type of ATC mechanism. Such a spindle design can be easily found from most Taiwanese VMC machine builders. Another important factor to influence the stiffness is the spindle diameter.



Umbrella type (left), Arm type ATC (right) < Supermax >

VICTOR Vcenter series VMC

Machine Weight

As mentioned above, the machine would have to be a more massive design to improve stiffness and will increase the machine weight. However, by only increasing machine size, it will not guarantee the machine rigidity. The wall thickness of the column, and rib thickness for the cast parts ie; the machine base, column, headstock and table must be strong enough to endure the cutting load. This increased mass makes the machine heavier and heavier. (*Weight is very important to many prospects and customers)*. In addition, the servo motors for the three axes must by upgraded to offer sufficient power and this also affects the machine cost.

Fixed Column or Traveling Column?

Traveling column C-frame machines are best suited to applications where high production volumes are required, or where very large, heavy parts must be accommodated. They provide the user with excellent access to the work area, and can be setup with several independent work zones through the use of software or hardware fences allowing work to be setup in one zone, while machining continues in the other. They are also well suited to automatic work changing systems, as only the Z-axis needs to move to

clear the work and to facilitate the pallet change. *(Victor has launched one new model Vcenter-205 for such a designed machine in 2003 for TIMTOS show in Taipei.)*

Stiffness and geometric accuracy are decreased in a traveling column machine because of the axes are typically located very far away from the tool-work interface. Because the entire column assembly must be carried by X- and Y- axes, dynamic performance is reduced and the acceleration are limited relative to a comparably sized fixed column C-frame. The following table is useful for the customers to consider which kind of column design is required for their frequent cutting applications.

Characteristic	c-Frame –Fixed Column	c-Frame –Traveling Column	Gantry Bridge	Fixed Rail Bridge	Ram – Fixed Column	Ram – Traveling Column
Stiffness	★★★★	★★	★★	★★★	★★	★½
Geometric Accuracy	★★★★	★★	★★	★★★	★★	★½
Thermal Stability	★★½	★★	★★★	★★★★	★★	★★
Dynamic Behavior	★★★★	★	★★★	★★★½	★★	★
Cost	★★★★	★★	★★	★★★★	★★★★	★★
Suitability for small parts	★★★★	★½	★★	★★★	★★★	★★
Suitability for medium parts	★★★½	★★	★★★	★★★½	★★★	★★½
Suitability for large parts	★	★★★	★★★★	★★★	★★	★★
Operator Access	★★★	★★★★	★★★★	★★★	★★★★	★★★★
Workpiece Changing	★★	★★★★	★★★★	★★★	★★★	★★★★
Auto. Tool Changing	★★★	★★★	★★	★★	★★	★★
Ranking: small, or medium parts	★★★★	★★	★★★	★★★★	★★★	★★½
Ranking: large parts	★★½	★★★	★★★½	★★★½	★★½	★★★

Table 2-4:
Suitability of 3-axis VMC designs for high performance machining. '★★★★' represents the highest ranking, '★' the lowest. Rankings for large parts are lower on average because of the difficulty in achieving tight tolerances on large complex components relative to small or medium parts.

Fanuc Controllers

Fanuc has released many types of controllers for various applications. The general ranking is 16 > 18 > 21 > 0 and Fanuc 16 control is only necessary when 5 axis (or more) simultaneous control is required. Fanuc also offers another cheaper model "D" (0M-D and 21M-D) with half pad keyboard which is very inconvenient for the operators and only suits to line production with routine manufacturing (where only cycle start button is required). Whatever the control model is, the most important "Data transfer rate (by DNC)" and "look ahead control" are the most important factors for the customers:

- ***Data transfer rate by DNC*** is important for mold manufacturers when the program is transferred from PC to controller when machining. The standard transfer rate for RS-232C is 19,200bps and installing the "remote buffer" (for old 0M-C control) can upgrade to 57600 bps. However, all the programs can be pre-loaded through Ethernet from PC to the "data server" (for 18MC, by network cable) or by inserting an ATA card (flash card) on the controller 18i/21i before starting machining. ***Remote buffer*** *has been phased out by* ***data server*** *(with* ***hard disk*** *or* ***ATA card).***.
- Whatever the programs are uploaded to the controller (by DNC) or pre-loaded inside the controller, ***the "look-ahead block" processing capability is even more important than "data transfer rate"*** because the feed forward control determines the maximum cutting feed rate and thus the total machining time.
- ***Conversational function*** (like Fanuc **"Manual guide i"**) is very popular for the mold workshops. However, this function is not very required in case the customers have already purchased CAD/CAM software.

Fanuc control models	**0M-C**	**0i-MA/MB**	**21i-MB**	**18M-C**	**18i-MB**
Feed forward control (for High Speed Machining):					
No. of look-ahead blocks	1	12 / 20	40 80 (opt.)	40 (AICC) ***(Victor std.)*** 180 (HPCC)	180 (AI η CC) 600 (AI HPCC)
Data transfer rate (for DNC):					
RS-232C (19,200 bps)	STD	STD	STD	STD	STD
Remote buffer (57,600 bps)	Opt.	NA	NA	NA	NA
Ethernet (10M bps):	NA	Opt. (by Data server *card)*	Opt.	Opt.	Standard
Data server (HDD)	NA	NA	NA.	Opt.	Opt.
Data server (Flash ATA card)	NA	Opt.	Opt	NA	STD
Color LCD graphic display:	NA	Opt. (Victor std)	Opt. (Victor STD)	Opt. (Victor Std.)	Standard (Victor- 10.4")
Conversational functions (for mold workshop):					
Manual guide "0i"	NA. (0M-F)	Opt.	NA.	NA.	NA.
Manual guide i	NA	NA	Opt.	NA (opt. *Super Cap*)	Opt. ***(Victor's STD)***
AICC: AI contouring control. **HPCC**: High Precision Contour control using 64-bit ***RISC*** processor					

Spindle Type and Speed

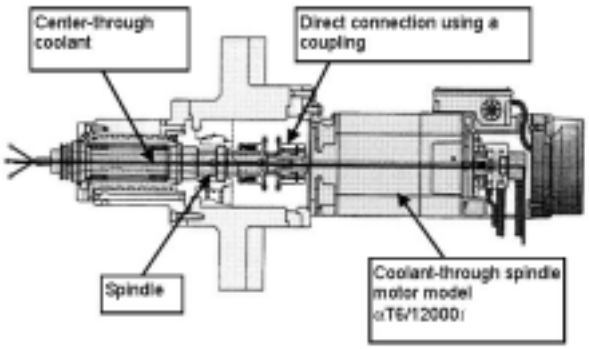
Heat build-up, vibration (noise) and dynamic balancing are three main factors to affect the maximum spindle speed and the following table shows these differences for various types of spindles for different speed applications.

Features \ Types	Belt-driven spindle	Directly coupled spindles (DCS)	Built-in spindles (Directly driven DDS)
Fanuc motor type	@i, @Pi	@Ti	@Bi
Spindle rotation speed	Low	Higher	Highest
Victor's spindles	4500/6000/8000/ 10000*	10000~12000	14000/15000 (BT-40) 20000 (HSK-A63)
Output at low rpm	By gearbox or by wide-range motor (aP)	By dual winding	By dual winding
Spindle vibration / noise	Highest (belt noise)	Higher	Low
Spindle heat-up	Low	Higher	Highest
Spindle motor cooling	Outside the headstock	Outside the headstock	Inside of headstock
Maintenance & service	Easy	Difficult	Most difficult
Cost	Low	Higher	Highest

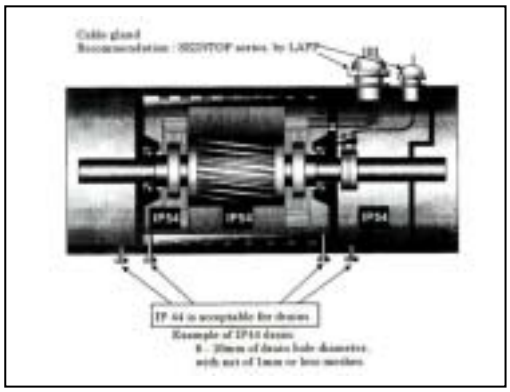
**The noise level for 10000rpm belt-driven spindle is around 80 dBA which is the allowable limit.*

➢ **Directly-coupled Spindles (DCS spindles)**

The spindle motor is directly connecting to the spindle by using a **coupling** and the hollow shaft of the motor enables the highly efficient center-through coolant machining. The transfer of heat produced by the motor to the spindle is minimized and each of the motor and spindle can be maintained separately.



DCS spindles are also named as "**IDD spindles**" by some competitors. The maximum allowable spindle speed is 12000rpm because of high difficulty on the coupling assembly as well as spindle dynamic balancing.

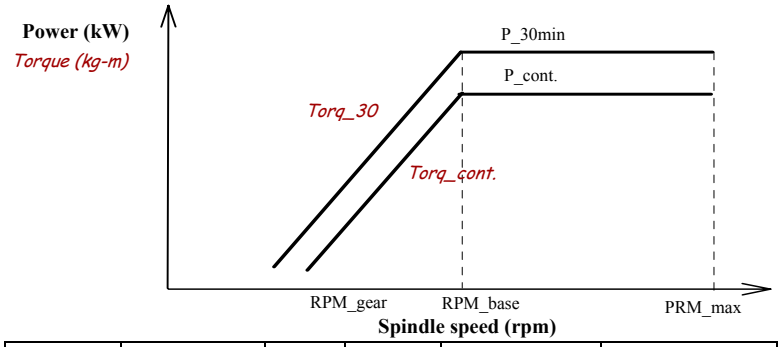


➢ **Built-in Spindles (DDS spindles, Motorspindles)**

Built-in spindle motor is an electric component including the stator and rotor to generate the high speed revolutions. Liquid cooling (oil cooler) is required to remove the high heat dissipation as well as to assure the rated output. Grease lubrication is more popular because of lower cost and additional oil mist device is required when the spindle speed is higher than 15000rpm for the bearing lubrications.

Higher spindle speed is the technical trend for better surface finish and high speed tooling is required to reduce the cutting impedance to increase the cutting efficiency. Our recommendation is to purchase 10000 rpm belt-driven machine if spindle is always running at 8000rpm and 12000 rpm DCS spindle if the spindle speed runs mostly at 10000rpm.

"KW" (Power) is NOT so important



Model	Sp. motor	RPM _base	RPM _max	P_con./30min (kW)	T_con./30min (kg-m)
Vc-55/70	**α6**	***1500***	8000	5.5 / 7.5	3.57 / 4.86
	αP12/8000	***750***	8000	5.5 / ***7.5***	***7.14 / 9.74***
	α8	1500	8000	7.5 / ***11***	***4.86 / 6.62***
VC-85	αP12	750	6000	5.5 / 7.5	7.14 / 9.74
	αP15	750	6000	7.5 / 9.0	9.74 / 11.69

Another misleading specification shown in the brochure is the horsepower of the spindle motor. Fanuc offers many types of spindle motors which are all named "α" models. The most commonly used spindles for vertical machining centers are the "α type" and "αP type". The α type is usually used for the spindle WITH A GEARBOX because the base speed is higher than αP motor (Fanuc wide range). For example, α6 and αP12 motors both offer 7.5kW but the torque for α6 is only half of αP12! Another instance can be referred between α8 and αP12. The α8 motor has 11 kW which is higher than αP12 with 7.5 kW, but the torque is even smaller than αP12!!

The tapping capability for Vcenter-55 with spindle motor α6 is just M20. However, if αP12/8000 motor is installed, the tapping capability can be upgraded to M30! Therefore, the customers should consider the importance of torque output rather than just the horsepower. The ***"true cutting capability" is dependent upon torque rather than horsepower!*** (This is similar to car driving. The output torque is more important than the engine size when the driver requires speed or acceleration.)

Fanuc has updated the spindle motor from "α type" and "αP type" to "αi type" and "αPi type" in 2003 to offer the enhance torque output at low rpm. We have also upgraded this new type motor on all Vcenter series machining centers accordingly but the basic concept on the torque and power output is nothing changed.

Standard and Optional accessories

There are many factors that influence the price of a Victor (Fortune) VMC; the bottom flushing system with high pressure or large flow rate, telescopic cover design to protect the axes, spindle oil cooler to prolong spindle life, tool numbers for the magazine, guarding to assure minimal coolant leakage…the list goes on.