Benchtop versus Small Knee Mill

– a user's perspective: pros/cons, and recommendations

This is a big topic, and I am certainly no expert, but I have owned both types of milling machines and logged hundreds of hours on each. What follows reflects my direct experience with this equipment.

Benchtop Mill/Drills

Rong Fu in Taiwan popularized the benchtop mill/drill alternative to the conventional knee mill (typified by the Bridgeport line). These benchtop mills, in addition to performing like a benchtop drill press also have the necessary bearings and spindles to handle the side loads associated with milling operations. They come in two basic varieties: round column (similar to most drill presses) and square column. The round column versions are fine as a drill press, but severely lacking as a mill because the spindle looses its registration when the head on the mill is moved up/down. The RF-30 and RF-40 typify this type. The "Square Column" or "Dovetail Column" benchtop mill maintains spindle registration to the XY table when the head is moved up/down on the column and is thus more suited to milling operations, or where consistent spindle registration is required. The RF-45 typifies this type.

Round Column Mill/Drill

Square Column Mill/Drill

Why is spindle centerline registration important?

- Imagine you're drilling and tapping a hole. The drill chuck with drill bit will need something like 6-8" of spindle height above the table or vise holding the material being worked on. After you drill the hole, then the hole must be threaded with a tap. The tap, often held in a collet, is so short compared to the chuck and drill bit, that the head must be moved downward several inches to complete the tapping operation. With a round column mill, when the head is lowered, the head is likely to rotate slightly on the round column so the tap is no longer aligned to the center of the hole you just drilled.
- You would be forced at that point to attempt to re-center the spindle over the hole, which could be impossible depending on the clearance for the necessary edge finders. Failure to re-center the spindle would be just begging for the tap to break inside the piece being threaded.

- This is just one example, and there are countless other situations where the head on a benchtop mill must be moved up or down between successive operations. A square column mill will maintain spindle registration when the head is repositioned, a round column mill will not.
- The same operation on a knee mill (bringing the material closer to, or further away from the spindle nose) is accomplished by moving the XY table up/down since the head position remains constant. The "Knee" on that type of mill is the platform for the XY table, and it moves up/down on a dovetail column and maintains registration of the XY table to the spindle centerline.

For many years, Rong Fu was the sole manufacturer of benchtop mill/drills, all made in Taiwan to reasonably high standards of components, fit and finish. Several companies OEM'd the Rong Fu brand under their own labels (Enco, Powermatic, Jet, etc.) and it didn't take long, once mainland China opened up for them to clone the designs and start offering them through distributors like Grizzly. In general, the Taiwan-made machines are built to higher standards of fit/finish, higher quality of spindle and bearings, hardened tables and surfaces that slide against each other, etc. And they cost more as a result.

Today, there are several manufacturers in Taiwan making benchtop mill/drills, but they come into the USA via importers like Precision Matthews, Grizzly, and several others. They are all variants around the same design, with the biggest differences being size, how the spindle is driven, and how speed changes are accomplished. The term "RF45" is now generic for "square column" benchtop mill and could mean lots of things when it comes to size, weight, cost and capability.

The more basic benchtop mills, even with square column, are belt driven and speed changes are made via belt position changes, or they substitute a variable speed motor at a sacrifice in low speed torque. The more advanced versions of the benchtop mills have a geared head (think of it has a manual transmission) where levers select different gear combinations to vary the speed. Some even have powered down-feed - meaning the spindle can be driven downward under power automatically at specified rates (this can be very handy when drilling hard materials like steel). The Rong Fu 45 has a geared head, and the 45-N2F model also has power down-feed. Some models have single-phase motors, others have 3-phase motors, and one variant has a 3-phase 4-pole motor that is capable of 3000 RPM top spindle speed. It is easy enough with any 3-phase RF-45 (or clone) to add a $300 VFD on the side of the mill, power the VFD with single-phase 220VAC, and achieve true variable speed, and spindle speeds up to 2,500 RPM even with the standard 2-pole motor.

There are also variants in the size and capacity of the RF45 - "baby", "junior", and even larger capacity "super" RF45's from various manufacturers and importers (PM-940 being an example). Specs vary and tell the story, so look closely. For example, Precision Matthews and Grizzly sell miniature Chinese versions for under $2,000 that weigh 300 pounds, and they also offer super-sized versions that weigh 900 pounds (150-percent of what an RF-45 weighs) at just under $4,000 and made in Taiwan. There is at least one European manufacturer (Wabeco) making benchtop mills. These mills are high quality, but expensive and small light-duty machines.

In general, the rigidity of a mill is proportional to the weight of the mill. The rigidity of each machine is directly related to its ability to remove material and yield high quality surface finishes. There are exceptions, but the more robust the machine, the more aggressive it's milling capabilities. All of these benchtop mills will machine aluminum, but if aggressive milling of steel or other harder materials is required, a heavier and more robust machine is ideal.

Another variant is the spindle taper and the type of tooling the mill can accept. Most drill press machines have a Morse Taper spindle, probably an MT3, MT4, or MT5. Some of the smaller benchtop mills will have an MT3 spindle. The larger benchtop mills will have an R8 spindle, which is compatible with Bridgeport tooling. For example, the RF-31 (replacement for the round column RF30) is offered with either an MT3 or R8 spindle. In general, the more metal machining being pursued, the better an R8 spindle will be in the long run simply because of the wide assortment of tooling available for that type of spindle.

The primary advantage of the benchtop mill over the conventional knee mill is smaller space requirement, cost, and weight. Compared to a full sized knee mill, the benchtop mill is a lighter duty machine, less capable of hogging off metal in milling operations. Most benchtop mills have a 1.5 or 2HP motor, whereas most full sized knee mills have 3-5 HP motors and more substantial quills/bearings, etc. Also, a large benchtop mill weighs 600-1,000 pounds (depending on version), whereas a knee mill is typically 1,500-3,000 pounds. With the right stand, a benchtop mill can fit in a shop with constrained ceiling height, whereas the shortest knee mill I have seen (the one I own) requires a full 82" of ceiling height, but more typically a knee mill requires 90-inches of headroom.

Knee Mills

There are two basic knee mill design types/philosophies – the USA type and the European type. Briefly, the European type has a table on a knee that goes up and down. The table travels in the side-to-side direction (X-axis) only, and the head moves in and out (Y-axis) on a motorized ram. Deckel and Schaublin are typical of this variety and they were made in various sizes and capacities, and are highly prized for their integrated power feed, robustness and accuracy. They do come up on the used market in the USA, but are expensive and require unique tooling for the spindle (neither R8 nor MT). Europe is a better source for used Deckel and Schaublin machines.

A quill head was optional equipment on Deckel mills, and many found in the used market do not have a head with a quill (that raises and lowers the spindle like a drill press). The spindle is thus fixed in position requiring the knee to be moved upward for drilling or other Z-axis positioning, and this can be a distinct disadvantage in drilling, tapping and other similar operations. Most of these machines are equipped with a table that tilts and/or swivels for compound angle drilling/milling operations. FPS in Europe purchased the rights to Deckel designs and will make one to order and even help with shipment to the USA – but at a significant cost approaching $50,000. (https://tinyurl.com/sffnmjk) Oddly enough, Knuth (a German company) manufactures a Deckel-style mill in China which is available in the USA by special order.

German made Deckel FP2 Knee Mill

The USA types of knee mills were popularized by Bridgeport Crop, and most of the new knee mills available today are variants of that original design. The design philosophy here is that the XY table moves in both directions (right/left and in/out) relative to the spindle, and the spindle is housed in a quill that will move up/down like a drill press. The table is mounted on a "knee" (hence the name) that also moves up/down on the column of the mill. This type of mill is by far the most widely used in the USA – Bridgeport having sold over 350,000 of them before going out of business. The Bridgeport name was purchased by another company, and new machines are offered under that name, with major parts and assemblies made in China. These new "Bridgeport" mills are about twice the price of an equivalent Asian-built knee mill of similar size.

Bridgeport-style Knee Mill with J-Head

To my knowledge, the only other company in the USA currently manufacturing a manual knee mill is Wells-Index. All the other new machines of this type are made in Taiwan or mainland China. Reconditioned Bridgeport machines are also available, but I quality of the restorations should be scrutinized. There are also quite a variety of Bridgeport-style mills available on the used market in just about every condition. If you are not familiar with how to evaluate the condition of a used mill, you may be setting yourself up for a risky decision unless you pull in the help of someone experienced in evaluating the condition, and advising on necessary reconditioning steps to bring it into good service.

Today, knee mills also come in several sizes and capacities. Several companies in the USA import clones of various knee mill sizes including Grizzly, Acer, Kent, Precision Matthews, Knuth, etc. For the purposes of this document, only the higher quality machines made in Taiwan are discussed.

Compared to the benchtop mills, a knee mill will typically larger XY tables, and also have slightly increased X and Y table movement specs. There are versions available with 40, 50 or 60-inch long tables. Some have 3HP or 5HP motors, and some are available with CAT or ISO 40 tooling spindle instead of R8. Lots of variations are available. Maximum distance from the top of the XY table to the bottom of the spindle nose (referred to as Z-height) varies but is typically equal to or considerably larger (if a riser-block is fitted to the column) than an RF45 clone. With the exception of the Wells-Index mills, almost all of knee mills have what is called a J-head - which is basically the same head design originated by Bridgeport in the 1930's. More on that below.

My Experience With Both Types of Mills

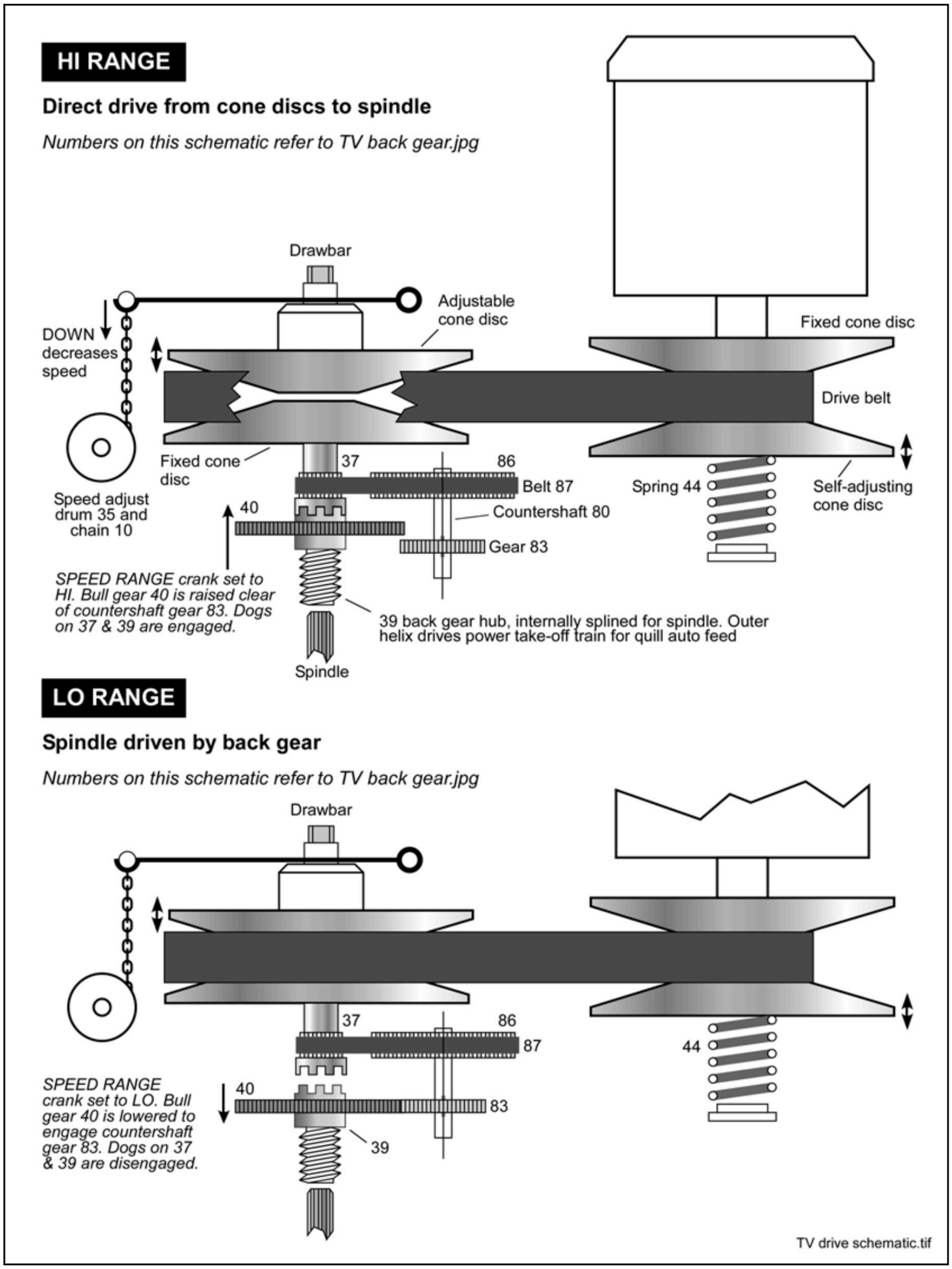
With my RF-45 N2F, I have been able to machine just about every type of material I've thrown at it. I have done lots of machining of tool steel, stainless steel, etc. and plenty of aluminum. My RF-45 had a 4-pole (meaning two-speed) 3-phase motor, and through the selector levers, was capable of speeds from 60 to 3,000. The RF-45 is an amazingly robust small milling machine. I sold it to make room for a junior-sized knee mill, and there are days when I regret that decision.

I have mixed feeling about the manual knee mill. Some aspects of these machines are superior to the largest/most robust benchtop mills, while other aspects are no better or even a step backwards in my opinion. I am particularly critical of the J-heads on these mills. The design hasn't changed or improved for almost 100 years, and in comparison to the geared head on the original RF-45 for instance, they are positively crude designs. Yes, people say Bridgeport mills with J-heads are the "world standard" and many people know how to use them and maintain them. But I have found three aspects of a Brigdeport-style knee mill that are particularly frustrating.

- First is the way the head attaches to the main column of the mill. The head is held out on a cantilevered arm called a "Ram" and this Ram can be repositioned to move the head in or out, perpendicular to the XY table, and once positioned, the Ram is locked in place prior to machining operations. This design provides for a static increase in the Y-axis envelope (distance from the mill column to the spindle). The head is attached to the Ram with a universal joint called the "Knuckle". This facilitates tilting the head sideways and up/down (called "nod") giving the head pitch and yaw flexibility for drilling at compound angles. To be sure, the Ram and Knuckle give added capacity and adjustment flexibility, but at a sacrifice in rigidity (ability to maintain alignment and dampen vibrations under load). In my experience, a large square column benchtop mill like the RF45, where the head is directly attached to the column with dovetails rather than cantilevered out on a Ram, is more rigid than the Bridgeport head configuration.
- Second, spindle speeds under about 400 RPM require the engagement of what's called the "back gear". This is a speed reduction system, which when engaged, lowers the spindle speed a factor of ten, and also reverses the rotation of the spindle - you have to remember to run the machine in the reverse after engaging the backgear. Engaging the back gear requires several clunky steps and is error prone, and disengaging the back gear can be troublesome.
- The third aspect of the J-head I find objectionable is the complexity and use of the power down-feed system. This system is quite the Rube Goldberg contraption of teeter-totters and levers and push rods, a real pain to use in contrast to the power down-feed on a geared head benchtop mill.

The knee mill I purchased is the smallest and lightest weight Taiwanese-built manual knee mill I've come across - basically a 4/5ths version of the original Bridgeport except for the motor and head: the Precision Matthews PM-935TS (https://www.precisionmatthews.com/shop/pm-935ts-tv/). The "T" means it was made in Taiwan, the "S" means the speed changes are done via a belt-position change (or optional VFD and 3-phase motor configuration). The PM-935 weighs 1,500 pounds and costs under $6,000. I have made substantial upgrades and customizations to that mill, chief among them the addition of a new electronic control system with VFD driven motor for infinitely variable speed changes without belt position change requirements. The new electronic controls also facilitate some advanced features such as auto-reversing back gear, and auto-reversing power down-feed (for tapping operations). Complete details on the upgrades (which included complete disassembly and re-painting) can be seen here: (https://flic.kr/s/aHsmzDiT4t)

That same PM-935 mill is available in a variable speed version as the PM-935TV with a mechanical Reeves belt-driven speed altering head unit. This simplified drawing, taken from the users manual for the 935TV illustrates the variable diameter cone-shaped drive-pulley system on this machine. This kind of mechanical variable speed system has been in wide use for decades. It functions well, however belt replacement is an arduous and difficult chore. This diagram also illustrates the back gear function for a 10:1 speed reduction which is common to all J-head mills and the primary means of attaining spindle speeds under 400 RPM.



Which Compact Milling Machine Makes Sense Today? (early 2020)

The PM-935 is an excellent choice for a baby Bridgeport-style knee mill. For the price and the compact size, it's an interesting alternative to the benchtop category. However, in my use, it has proven to be less rigid and more temperamental than the RF-45 mill/drill it replaced. Plus, it comes with the J−head-style head and all that comes along with that (see previous section).

I was able to get better surface finishes with the RF-45 in stainless and tool steel. I can push the PM-935 slightly harder than the RF-45 in terms of material removal rates (cubic inches of material removed per minute) by about 120 percent, but at a sacrifice in surface finish quality and tolerance to target dimensions. If the PM-935 is pushed too aggressively, the head is thrown out of alignment and must be realigned (called "tramming"). This behavior is something I never experienced with the RF-45.

Intuitively, I conclude this is attributable to the head attachment via the Knuckle and the attendant Ram. I have also proven through the use of indicators against the heads of both machines, that the head on the PM-935 can be flexed up or down a few thousandths of an inch by hand pressure, whereas the RF-45 head would not deflect under similar hand pressure.

Adding the Ram and Knuckle to the machine can provide extra reach and drilling angle flexibility, but at the cost of rigidity compared to a larger square column mill/drill like the RF-45 or others currently available. The idea that a benchtop mill is less rigid than a knee mill is a fallacy in this case.

Key Specifications of Popular Compact Milling Machines

Key Specifications - Taken from Published Information						
		Bench top Mill			Junior Knee Mill	
Model		RF-45	PM-833T	PM-833TV	PM-935TS	PM-935TV
Motor Type		1- or 3- phase	1-phase	3-phase	1- or 3- phase	1- or 3- phase
Motor HP		1.5	2	2	3	3
Speed Range		60-1500 1-phase. 60-3000 3-phase	60-230, 450-1500 with belt change	50--3200 single position belt	80-600 in Back Gear 400-2720 Normal 50-5000 w VFD	60-500 in Back Gear 500-2700 Normal
Speed Change Selection		Geared Head 1-phase 6-steps, 3-phase 12-steps	Geared Head six steps	Proprietary VFD	4-Step Belt Change or VFD	Reeves Mechanical Variable
Head Type		Geared Head, Power downfeed options	Geared Head with Power Downfeed	Belt Drive with Power Downfeed	J-Head Belt Drive with Power Down/Up Feed	
Spindle Taper		MT3 or R8	R8	R8	R8	R8
Table Length	X	32.25	33	33	35	35
MaxTable Movement	X	20.5	21.75	21.75	24	24
Max Table Movement w Power Feed	X	18	19	19	22	22
Table Width	Y	9.5	8.25	8.25	9	9
Table Movement	Y	8.25	11	11	12	12
Quill Travel	Z	5	5	5	5	5
Head or Knee Travel	Z					
Maximum Z-Height (spindle nose to table)		18	20.5	20.5	17	17
Spindle to Column		10	11.25	11.25	4 to 15	4 to 15
Weight in Pounds		750	900	750	1430	1500

What the PM-935 does have that the RF-45 does not, is the availability power feed add-ons to the XY table in Y-axis Having a power feeder on the Y-axis of the table is huge convenience when squaring stock and bring material to finished size. Adding power feed to the X-axis on an benchtop mill is a $300 proposition. Adding power feed to the PM-935 is a similar cost for each table axis and for the knee.

The biggest frustration I encountered with the RF-45 was the hand crank to move the head up/down, and there was no easy way to add power feed to the head elevation on that machine. The newer benchtop design typified by the PM-833T has a different head elevation system and optional power feed units are available for a reasonable cost (see discussion below).

The original Rong Fu 45 is still available, but none of the importers provide post-sales support, and the cost of the machine has gone up considerably, so it is no longer competitive. Very infrequently the RF-45 comes up on the used market – they are prized for their quality and general utility as both a drill press and lighter-duty milling machine. Only the 2-speed 3-phase motor version of the RF-45 is capable of speeds above 1,500 RPM unless a VFD is added. And only the N2F designated RF-45 has power down-feed.

If I were buying a compact mill today, I would most likely purchase the PM-833T or PM-833TV (both made in Taiwan like the Rong Fu machines) from Precision Matthews. (https://tinyurl.com/y68kh49h) I would choose the PM-833T over the PM-935 junior-size knee mill for the simple reason that the geared head unit is a better design and the machine should perform just as well. Have a look at the differences in the specifications and choose wisely.

Compared to the original RF-45, the PM-833T machine has slightly larger table size and 3-inches of additional travel in the Y-axis (which is a important distinction on a benchtop mill), and weighs a hefty 900 pounds without the stand – fully 50-percent heavier than the RF-45 from Rong Fu.

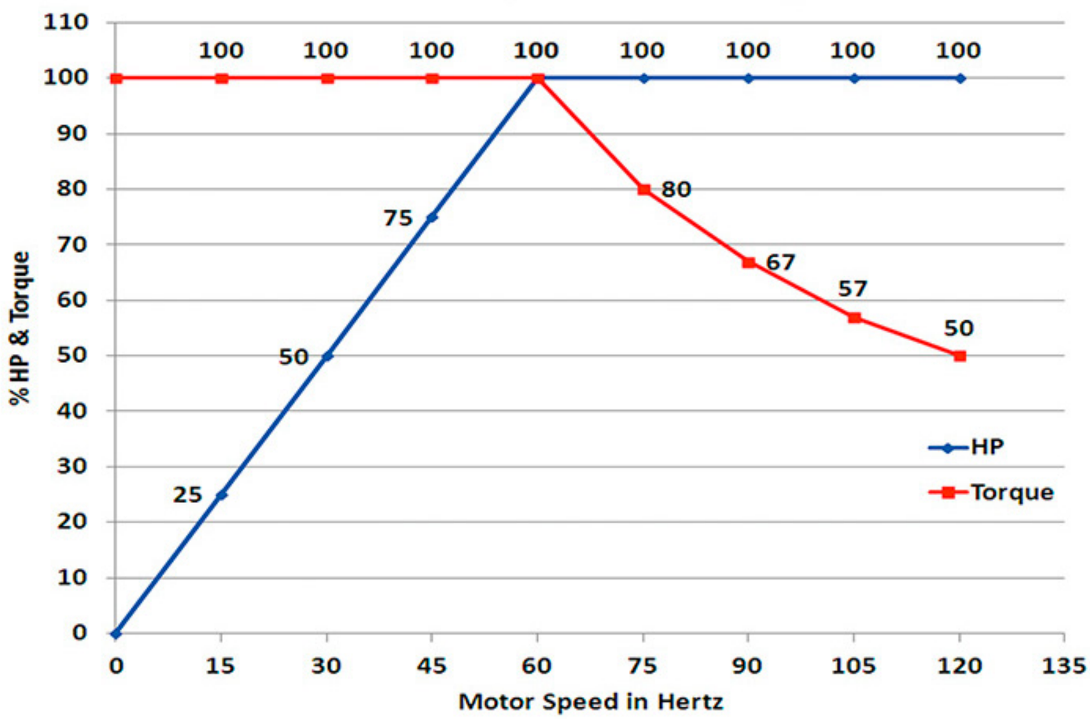
But there is one other significant difference: how the head is moved up/down. Like the RF-45, the PM-833 head can be raised and lowered via a hand crank on the side of the column. The RF-45 head elevation system is a rack & pinion setup which is quite stiff and awkwardly positioned on the left side of the column, whereas the PM-833 has a worm gear system that is easier to access and operate, and is compatible with an optional power feed unit to motorize the raising and lowering of the head. Like the RF-45, the PM-833 has an R8 compatible spindle, which opens the door to all the Bridgeport-style tooling.

There are two versions of the PM-833, each appropriate for slightly different needs. The PM-833T is a geared head machine, with speeds of 60-1500 in six steps simply by changing lever positions, and is powered by a single-phase 2HP motor. In contrast, the PM-833TV is a single-position belt-driven machine and is powered by a 2HP 3-phase motor that is controlled via a proprietary VFD. The advertised speed range is 50-3200 RPM, with corresponding diminishing power at both extreme ends of that range.

What is the trade-off here? The geared head 833T will have much better low-end power compared to the 833TV. From a practical perspective this distinction simply means that the geared head machine will be better at aggressive drilling and milling into hard metals like steel, or larger diameter powered tapping operations in to steel or other hard metals. If drilling ¾" holes in ½" thick steel, or aggressively running shell or face mills is not a requirement, the low-speed power reductions on the 833TV may not be an important distinction. Not having direct experience with the 833TV, it's hard to say, but the 833TV should perform adequately machining aluminum, but perform less well in harder metals compared to its geared-head counterpart, the P<-833T.

On the positive side for the 833TV, being belt driven, it will be quieter in operation than the geared head machine. And the high-speed range of 3,000+ RPM is certainly an advantage when machining aluminum, or other soft materials. It is worth mentioning that the belt-driven head on the 833TV is approximately 150 pounds lighter in weight (based on the published specs on the Precision Matthews web site), which might also indicate that in practice, the 833TV might be less rigid than the geared head 833T counterpart. This is pure speculation on my part, but worth bringing up in the comparison of the two alternative configurations; head weight contributes to rigidity.

Consider the following chart. To obtain the very slow speeds of 50-100 RPM, the VFD on the 833TV is driving the motor at 3-6Hz (three to six). The power available to the spindle is thus in the range of 10-20 percent of the rated motor horsepower.



This is the nature of VFD-driven motors that gives rise to my reservation about low-speed power for certain materials and operations using the PM-833TV.

At the time this document was written, actual user performance data was unavailable. In time, the true limitations imposed by this VFD-driven configuration will be better quantified with real user experience. For the wide variety of materials and operations I use a mill for, it strikes me that the geared head PM-833T, with a 3-phase vector-rated motor and conventional VFD would be the best of both worlds. As of this writing, such a configuration is not available.