PSG 612 Design Analysis

By Andy Grevstad, Greg Jackson, and Rory DesJardin; Tormach LLC

Executive Summary: Tormach PSG 612 Personal Surface Grinder

The PSG 612 is an affordable 6”x12” semi-automatic surface grinder targeted for hobby and small-batch production applications. Automatic table motion (X,Y) is provided by stepper motors, but can also be positioned manually with hand wheels; wheel head (Z) motion is manual. Dial adjustment provides continuously variable feed and speed control, while a simple control interface provides 4 preprogrammed automatic grinding patterns for table motion.

Forward

Wouldn’t it be cool…

Since very early on in the history of Tormach, we’ve held a weekly round table technical discussion every Friday. The meeting is a great incubator for ideas because it provides an open forum for our engineers, machinists, and tech support team to discuss ideas to improve our products and service to our customers. For this meeting, any idea that advances the company mission to our customers, *Enabling Your Ideas*, gets its moment under the lights. This meeting lasts 3 hours and often longer, but it’s rare for anybody to leave early and potentially forfeit their chance to weigh in what’s being presented. Discussion topics originate from a variety of sources – customer feedback on existing products, manufacturing issues with vendors, technical support issues that arise, or the latest cool YouTube video that somebody came across.

Tormach PSG 612 Personal Surface Grinder

The seed of the idea for a personal grinder started in a Friday meeting. A manufacturing problem from one of our vendors meant that we would need to contract out rework for a small batch of ground parts. It was frustrating because we knew that the fix was simple but because of the small quantity involved, the outside rework bids were expensive. Large shops with automatic grinder capabilities wouldn’t touch the job; it was too small. The small shops willing to take on small quantity rework were equally uninterested because they didn’t have an automatic surface grinder. This job was in no man’s land, so to say.

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Why not get a manual surface grinder and do the rework ourselves? "Sure," joked one of our machinists, "just make sure to hire somebody else to turn the cranks back and forth all day long – because I sure am not going to do it!" The discussion quickly evolved, from doing a bit of grinding ourselves, to making an automated grinder and the challenge was issued – "Why don't we make something that can spin the wheels by itself?" A good idea, perhaps – but surely something must already exist in the world – an affordable semi-automatic grinder would seem to have a lot of utility.

After a few searches, we realized that such a product just didn't exist. We knew that our own business could benefit from a surface grinder for occasional rework jobs and also for mechanical prototyping. But we also immediately thought of existing Tormach customers who could use just this type of machine. It would lend itself to endeavors in custom knifemaking, gunsmithing, and other business engaged in small batch production in a similar way to our popular PCNC 1100 and PCNC 770 milling machines. We also imagined that it might find some use in small tool rooms and maintenance shops, and within the model making community.

Putting the PSG 612 in Context

With a market identified, the biggest remaining challenge was to determine whether we could produce something that would be affordable to its intended audience but still capable of real work. Without that value proposition, it would be just an expensive toy and without real utility.

To put the PSG 612 in context, it's helpful to understand what other surface grinding options are available in the manufacturing world and elsewhere.

> ***Authors' Note:***
> *All product design represents a compromise. Product features like precision, ease of use, cost, and many other factors are measured in balance to find the optimum solution for a particular market. At Tormach we feel that sharing our engineering ideas is the best way we have to help a potential customer understand whether a machine is appropriate to their needs; whether our objectives in design and the balance we have struck suit their personal needs. This is the purpose of our design white papers. It's not a sales pitch, it's the story of a machine development. This story is about the development of our new semi-automatic grinder.*

Surface Grinders: A Brief Survey

Both Automated and non-automated surface grinders are used in manufacturing. More sophisticated automation is strongly correlated with large scale manufacturing, as opposed to batch part production.

Currently available CNC grinders are firmly positioned as production machinery. These machines use either closed-loop servo-driven ball screws or hydraulics to provide table and/or wheel head motion. They offer sophisticated CNC control with automatic wheel dressing, wheel wear compensation, tool path editing, and other features geared towards long periods of unattended operation and cycle time optimization. CNC grinders are also heavily customized for the particular factory installation. They are simply not practical for occasional small shop usage.

In a class below CNC grinders are automatic grinders. Compared to CNC grinders, these use simplified controllers. They are job shop machines – easy to program and easy to use; and designed for versatility and quick setup in lieu of unattended operation in a continuous production scenario. These machines are employed in job shops and other batch manufacturing scenarios.

What are leftover are manual grinders. They are affordable but time-consuming operate. The nature of their manual operation makes it non-trivial to achieve consistent and repeatable results.

One last surface grinding technology of note is an interesting relic of times past: the reciprocating or auto-feed manual grinder, made by Brown & Sharpe, Jones & Shipman, Reid, and others. As a mechanical curiosity, these are interesting

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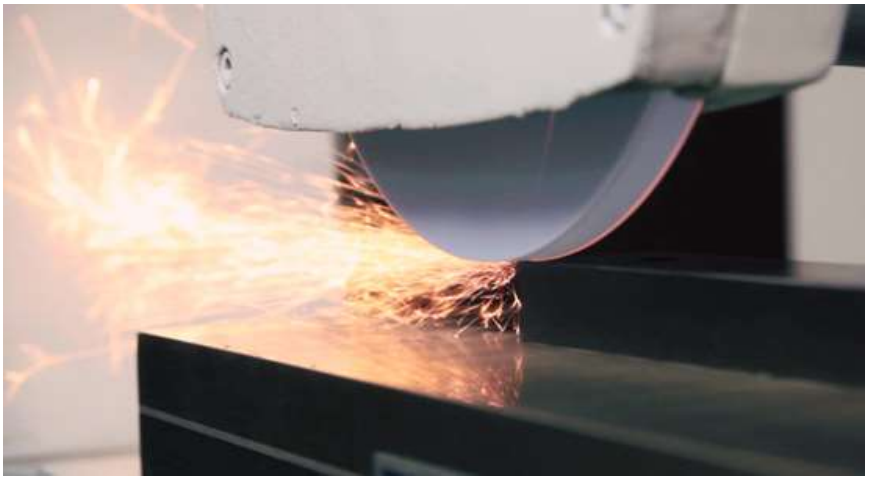
machines; they can still be found occasionally at old iron auctions. However, as with most pre-computer age designs, these prove to be expensive to fix and maintain because of the intricate and specialized mechatronics.

The "Personality" of a Personal Surface Grinder

When developing the PSG 612, we focused on the simplest automated surface grinders that are used in industry: 2-Axis (aka semi-automatic) surface grinders. We felt that the utility of these machines would translate best to the small shop environment for several reasons:



First and foremost is operator safety. 3-axis CNC grinders, and especially large grinders, have earned the respect of machinists. A simple programming mistake can shatter a wheel, or throw a work piece hard against the table guard. Eliminating automatic wheel head motion makes the PSG 612 much safer to operate since it greatly decreases the chance for an unintended collision. Limiting the spindle power to ¾ HP also mitigates the risk of throwing a part and causing damage to a level on par with consumer power tools. Power tools will always be inherently dangerous, however; a personal surface grinder shouldn't be disproportionately so with respect to the intended environment.

A second reason is operational scope. We felt that the most realistic uses for a small semi-automatic surface grinder would be essentially the same that can be accomplished with a manual machine with the advantage of leveraging the repeatability and consistent results that an automated process provides. The majority of work would be surface grinding to final dimension, or to meet a surface finish requirement, or perhaps to meet perpendicularity or parallelism specification. Profile (contour) grinding would be well out of scope, but form grinding could be done with a properly dressed wheel. With 2-axis automation, a small group of parts can be batch ground to a consistent thickness. Time-consuming grinding operation can be "set and forgot", freeing up time to work on higher value operations while leaving the crank spinning to the machine. Aesthetically, a consistent grind pattern can be imparted onto the work piece surface for a pleasing finished look, something that is not easily done with a manual grinder.

Design Challenges

The design cycle of any product is a series of challenges. Many are mundane, but all are consequential. As related to the development of the PSG 612, the following two design challenges merit further discussion:

Challenge 1: *Affordability*
Solution: *Finding Value in Familiarity*

As stated previously, a primary design consideration for the PSG612 was to keep the cost of acquisition as low as possible. Looking over what was available to small shops, it was clear that there was an enormous gap between small manual grinders ($3000 to $4000) and the lowest cost automatic grinder ($12,000 and higher).

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Our vision for the PSG 612 was a machine that would fill that gap - hopefully closer in cost to the manual grinders.

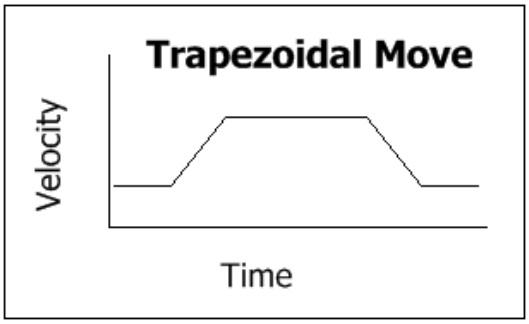
To that end, our strategy was to leverage as much of an existing manual surface grinder design as possible. This would allow us to take advantage of the economies of scale afforded by the larger marketplace for many of the component level parts, including the frame castings, helping us keep the price low. Essential and unique components, such as the control boards, motors, and drivers, would be designed and /or supplied by us to ensure product quality.

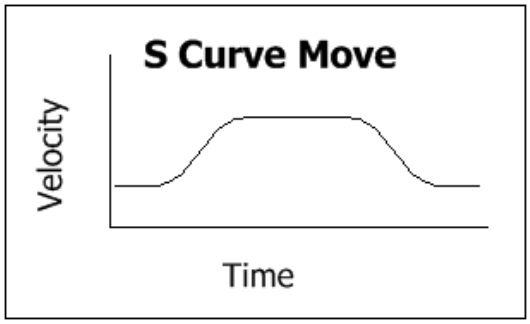
Final machine assembly would be done by our most trusted manufacturing partner; our long relationship and familiarity has given us confidence in their capabilities. It would also allow us to maintain the same effective QA measures previously established with our PCNC mills.

Challenge 2: *Smooth Grinding Motion*
Solution: *3rd Order Motion Control*

Technically, our biggest challenge was the development of a low cost motion technology system for the PSG 612. Nearly all the small automated grinders used a hydraulic drive system. This is done to provide the smooth motion that is essential to a good finish. It's also one of the primary cost drivers. Our experience with advanced polyphase stepping systems gave us confidence that we could build a lower cost motion system, but we were not certain it would be smooth enough for a surface grinding application.

Our proof of concept work involved modifying a manual grinder by adding 3 phase stepping motors and microstepping drives to the existing rack and pinion transmission. The system was then jury-rigged into a Mach3 control system. After working with the hacked grinder a bit, we found no pattern induced by the motor stepping frequency. We did find that using a Mach3 system for signal generation was insufficient for smooth operation. The core issue was that Mach3 uses a 2nd order equation for motion, commonly referred to as a trapezoidal move. The corner points, i.e., the beginning and end of the acceleration and deceleration phases, introduced vibration into the machine.





The solution was to develop an embedded controller that makes use of 3rd order equations. That yields a smoothed motion profile, commonly called an S curve profile. The difference in machine vibration is significant.

One final surprise was the fact that, under electronic control, we could create a feed rate significantly slower than a human operator could reliably produce. With our prototype, a light depth of cut and an extremely slow

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feed rate can produce a surface finish that would normally only be seen with a much heavier grinder. This paralleled our experience with the PCNC Mills. The general concept it can be expressed simply:

> *As long as you're not in a hurry, a good and accurate finish can be achieved by a relatively lightweight machine if it's built with a superior control system and modest spindle power.*

To state the obvious, the PSG 612 is not designed for a high volume production shop. Like the other machines in our Personal series, the PSG 612 is targeted towards small shops, short runs, inventors, R&D shops, and home shop machinists.

Technical Design Discussion

The following is a discussion of some the important design details of the PSG 612.

Frame and Axis

The final product is not simply a manual grinder with motors. A thorough review of the machine details rapidly led to the conclusion that the basic iron frame was the best solution, but the axis slide ways needed to change. Low cost manual grinders tend to use one of the following table bearing systems: iron on iron (with an oil film) or ball bearing glides. Iron on iron is the cheapest and probably adequate for a machine that is so tedious to operate it will likely never be worn out. Ball bearing glides are used, not for any increased accuracy but rather for reduced friction. Running a manual grinder can be tedious and tiring, hence the desire for free running table. This factor is far less important when there are motors moving the axis. More expensive CNC grinders intended for continuous production will often use linear bearings, but that approach would not yield an affordable design. Our experience with low friction hand scrapped slide ways on our PCNC mills has been very positive. These are oil lubricated slides. They are initially precision ground, after which a plastic surface is bonded to one side (Turcite®, Rulon®, or similar material). The machine is hand scrapped and oil passages are cut to get way oil into all the right places. The result is an extremely long lasting slide which is far more durable against occasional grit contamination than either all-metal slide or ball bearings.

Screws, Bearings, and Hand Wheels

Manual surface grinders typically have the Y –axis (cross feed) screw mounted on a couple of preloaded bearings and fitted with a hand wheel. If we had simply attached a motor, we would have needed two additional bearings (inside the motor), introducing potential for alignment issues since there would be 4 bearings on one shaft. Seeking the ultimate in economy and taking advantage of our relationship with the motor factory, we developed a Y axis motor which incorporated preloaded bearings inside the motor. There are no bearings on the screw itself. The result is fewer bearing pockets to machine, fewer bearings to wear out, fewer points of failure, and reduced manufacturing tolerance constraints since we no longer need coaxial alignment on 4 bearings.

With an eye toward simplicity we elected to use adjustable proximity switches to set table stroke in both directions. They are robust as well as simple to maintain and service. This design approach eliminates the need for referencing on startup and makes setup very intuitive. LED indicators show limit switch status.

With the Z-Axis, we elected to not automate wheel head and leverage the existing hand wheel and lead screw design present on the manual version of the frame. This was not only done for simplicity, but also for safety: erroneous Z motion can cause spectacular crashes on a CNC grinder that can be dangerous to the operator. One small but necessary addition that was made to the Z axis was the inclusion of a dial indicator that could provide a reference point for repeatable positioning. Our plan is to develop a fine adjustment attachment to as a future accessory.

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Both X and Y axes have hand wheels for setup and manual positioning.

Control System

After considering the type of work typically done with a surface grinder, we knew the best option for control would be the simplest. There really is no need for a G-code interpreter; everything needed for the control could exist on a PIC microcontroller inside the cabinet. This design is robust and easy to maintain, and we expect the PSG 612 to provide a lifetime of worry free operation.

We chose to use Leadshine® motion drivers to provide step and direction to both X and Y axis motors. This was any easy choice; we had previously completed a lengthy evaluation of these drivers prior to introducing them as the motion driver technology for our Tormach PCNC Series 3 mills and have been nothing short of impressed with the robustness and value they provide in the 2 years since.

Machine Specifications

PSG 612 Basic Machine Specifications	
Table Size	6" x 12"
Table Slot(s)	1 Slot, standard 1/2" T
Longitudinal Feed Max Travel	14"
Cross Feed Max Travel	8.75"
Min / Max Distance to Spindle Center	3" min, 12" max
Floor to table height	40"
Space required for full range of movement	51" W x 66" H x 30" D
Stand footprint	24" x 24"
Approximate shipping weight	720 lbs.
Weight	400 lbs
Crate Dimensions	44” W x 66”H x 32”D
Max Work piece	150 lbs.
POWER	
Power Requirements	Single Phase, 115 VAC 50/60 Hz 8 Amp Peak / 4 Amp Continuous 15A Breaker Recommended
SPINDLE	
Spindle Motor	Industrial grade 3/4 HP TEFC Induction Motor. Single Phase, 115 V 60 Hz
Wheel Size	7" x 1-1/4" x 1/2" (includes arbor)
Wheel Speed	3450 RPM (@ 60 Hz), providing 6300 SFM

PSG 612 Basic Machine Specifications (Continued)
MACHINE FRAME

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Frame and Table	Yard-aged Cast Iron, with hand-scraped hydrodynamic dovetailed slide ways and tapered adjustment gibs
Slide Way Surfaces	Low Friction PTFE-filled Acetyl bonded sliding surface, similar to Turcite® or Rulon®
MOTION	
Feed rate	0-45 ft/min Longitudinal (X) 0-24 ft/min Cross Feed (Y)
Axis Drives	NEMA 34 Stepper Motors with Leadshine® high performance microstepping drivers
Locomotion	Longitudinal: Rack and Pinion (automatic) Cross: Lead screw w/ anti-backlash nut (automatic or manual) Vertical: Lead screw w/ anti-backlash nut (manual)
Vertical Hand wheel graduation	0.0005" (0.012mm)
Cross feed Hand wheel graduation	0.001" (0.025mm)
CONTROL	
Operator Console	Wheel On/Off, Automatic Mode Select, Longitudinal Speed and Cross Feed Control, Power On, E-Stop
Automatic Feed Selection	4 mode automatic feed
OTHER	
Paint	2-part copolymer enamel, cross-linked acrylic /modified amino resin
Stand	Sheet metal with Storage cabinet and adjustable footpads
Lubrication	Single Shot distribution, 5 points
WARRANTY	
Standard Warranty	12 month Tormach Standard Warranty
Extended Warranty	12 month Optional Extended Warranty, Renewable yearly

In Summary

The PSG 612 grinder is uniquely situated, being far more than a small manual surface grinder, but far less than a heavy production grinder. We feel it's an excellent application of embedded systems engineering and brings the most important features of a semi-automatic grinder into a small shop at a price near that of existing manual surface grinders.

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