TMI's Dimensional Services Group Case Study

The Case for Laser Calibration of a CNC Machine

Lasers have been deployed on CNC machines and CMM's for a long time and in some companies and industries these instruments have become rather commonplace as a tool for maintenance groups. Industries such as aerospace, heavy manufacturing, and automotive rely on these tools to ensure among other things machine positioning accuracy. These tools are not only deployed in changing out machine parts that impact accuracy but are used routinely in preventive maintenance routines and in-process work. However, laser measurement systems are not commonplace for use on machine tools in all industries so one is forced to ask, what is it that is different about these industries that would cause them to invest in the equipment or service? Further, one might ask, "what is it that the people in these industries know that others do not?"

A number of aspects may be pulled from these industries that can lend some insight into their operations. We will first look at the part investment at the machining stages within these industries. We will then look at the operational efficiencies that are gained across all the industries and finally look at some real data coming from the machines.

Part Investment

In the aerospace industry, composites are growing in popularity and seem to be the direction the industry is headed in. Looking at the Boeing Company's new design for the 787, there is a high amount of composites content. Further evidence of this is Airbus' planned design for their new A350 XWB. As many are familiar, composite sections are typically laid up (there are a number of ways of performing this ranging from hand layup to a fully automated situation such as the 787 fuselage components) and then cured in an autoclave over time. During this time, the inherent resin within the cloth or filaments bonds with the composite and ultimately cures out. Once complete, the part is removed and must be taken to a trim cell of some sort to have the net part routed or certain cutouts removed.

Beyond the obvious differences from their metallic parts, composite parts are much less amenable to rework. Basically, mistakes at this point can be quite costly up to scrapping the part. At the time of the routing, industry engineers have estimated the investment in the part to be as high as 90%.
In terms of investment, the 787 program has upped the investment dollar amount even further by utilizing co-cured parts in its composite assemblies. Longerons (stringers) and other aspects of the assembly that were once installed utilizing fasteners are now cured with the composite assembly reducing not only cost but weight as well. While there are many efforts underway in the industry to lay parts up at net configuration to avoid the trimming efforts, most parts still require trimming.

Another collateral aspect of the composite use is increased use of titanium in aircraft structures. With composite structures, aluminum may not be placed directly against the carbon epoxy laminate without the use of some sort of a barrier ply (such as fiberglass) as without the barrier the assembly is subject to galvanic corrosion. Adding the barrier ply not only increases weight but cost as well since a different material must now be deployed in the layup process referenced earlier. Further, titanium offers structural advantages in weight and structural aspects over aluminum.

There is a downside to titanium however. Availability and cost are two factors in the downside. With this in mind, scrapping a titanium part is more costly than aluminum so again, the investment goes higher the further the parts travel through the machining process.

In the heavy industries and automotive where engines are being manufactured, the part investment is also very high. Large engine blocks are machined for crank bores, cylinder bores and other high precision operations. Mistakes at this stage mean many things including scrap (if the error is caught), lower engine life, lower performance expectations, and ultimately an unhappy customer. The industry leaders within this segment understand the impact that these things not only have to the bottom line of their operations but also the impact is has to their brand and customers. One of the first considerations for these industry leaders in any decision is whether the outcome will in any way damage the brand name of their product. This conventional wisdom may be seen as direct evidence in their stock price and happy customers.

Having inaccurate machines when the investment is this high is not an option. All stops are removed in these industries to ensure that as much of the risk is removed from the equation as possible. This ultimately makes financial sense when the ever rising cost of these assemblies is taken into consideration. Scrapping is not an option here.

Assembly Rework and Process Consistency

Another reason that all these industries maintain accuracy on their machines is rework reduction at the assembly level. Maintaining high degrees of accuracy at the part level reduces not only the assembly cycle time but the even more costly rework aspect of an assembly once a problem is found. Having products placed in a WIP status (Work in Progress) is not only costly from an overhead aspect (it can not be delivered until it is reworked), but pulls resources from the assembly level for repair which of course has some sort of opportunity cost associated with it.

Further, another aspect cannot be overlooked. Failure to increase accuracy at the detail part level introduces variation into the assembly process at the root level thus making it difficult to improve a process. As we will discuss later, you can not compensate for that which you can not repeat.

Having consistent machines through calibration will not remove all errors in a process. There are many more variables in a process – this simply removes one of them.

Operational Flexibility and Efficiency

There are many ways to get around an inaccurate machine in a shop. One way is to modify the program that makes the part to account for the geometric and positioning errors in a machine. For the most part, within the industries we are looking at here, there are processes that do not allow this to happen. The realization for them is that failure to adhere to these processes will violate the call for traceability back to a master definition and compromise operational flexibility.

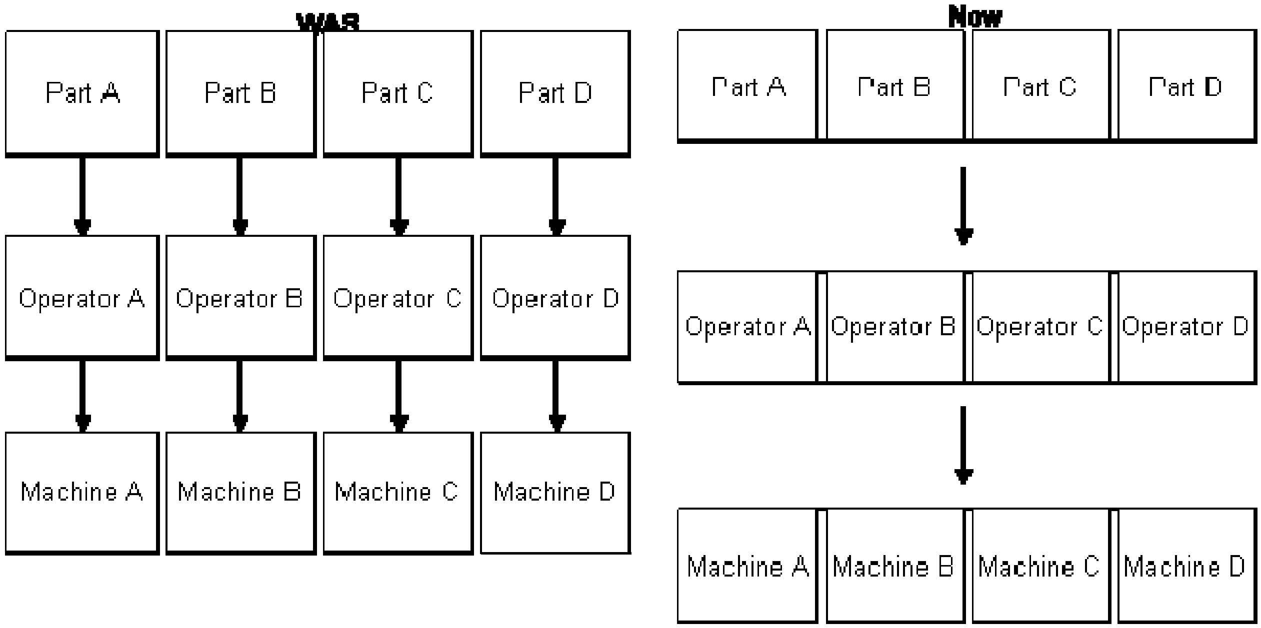
We all know that no two machines are exactly alike in not only their geometry but error and dynamic behavior as well. Modifying a program to work for a specific machine tool really means that, unless you are willing to go through the same trial process on another machine, you must make that part on the same machine. This puts operational stress on a manufacturing operation as the machine themselves become part of the critical path of the manufacturing process (as opposed to the operations associated with the manufacturing of the part).

Having a part tied to a certain machine severely limits the options for manufacturing the part and thus limits the options of the operation as a whole. This is not a problem for a facility that is operating at 33% capacity utilization (unless the machine goes down) however as we have all seen, companies that operate at this level of utilization often are not around very long. Ultimately, this practice can hamstring an operation and constrict growth opportunities. It can also end up in a lower efficiency within the shop and a lower bottom line as the shop is now forced to purchase new equipment to cope with the straight line options that are created by tying a specific part to a machine.

Another way to get around the inaccurate machine is at the operator level. It has been said many times, “if you want to know what is going on with a machine, ask the programmer and the operator”. In many manufacturing facilities, the operators and programmers are the unsung heroes who are charged with making parts on machines that are not capable. Often times, they make adjustments at the machine level to ensure the part produced will pass dimensional and quality inspection. I was once checking a machine in a facility and the operator told me, “I always approach the part from this direction because it seems to be more accurate. I checked it once with a dial indicator and found there was about a .005” difference so I always approach the part from this direction”. I then proceeded to show him the screen of the computer with the laser readings which confirmed his suspicion. This particular machine was rather large in size with box ways and a rack and pinion drive. Its rapid rates were not high. After speaking with the operator, we realized that he was typically adding as much as a half hour to the cycle time of his parts just because of this aspect. All this was done to make a good part. This is only one aspect that he realized. Later, other aspects of the machine were found that explained some of the non-conformances that he was seeing.

Another commonly overlooked aspect of having an operator who adjusts the machine to make a good part is that only that operator is able to make the part correctly and now only on that machine. Unknowingly, we now have two further elements added to the manufacturing critical path – first the machine, and now the operator. Many shops have been in the bind of the operator not coming in and not being able to deliver a part or even worse, using another operator and having a part rejected or scrapped.

Having consistent geometry on all machines gives rise to portability within an operation and ultimately opens the machine to greater utilization through improved scheduling options and less reliance on specific personnel as illustrated on the following page.



Examples of Insight into Machine Performance and Capability

While many are familiar with the idea of placing a laser on a machine, many are not familiar with the processes employed or even the data that may be retrieved. Further, understanding the data in relation to the machine's geometry and the machining process takes experience and a willingness to think in three dimensions.

The Process

Below is the general process that these types of measurements follow. This is typically independent of the machine geometry and its control. The details of the process will differ somewhat but the general process remains the same.

1. Remove/Zero Compensation in Control
2. Measure Axis with 3 Runs – 2 is sufficient if repeatable
3. Compensate the axis by generating compensation file in accordance with control
4. Re-measure axis to ensure compensation is correct.

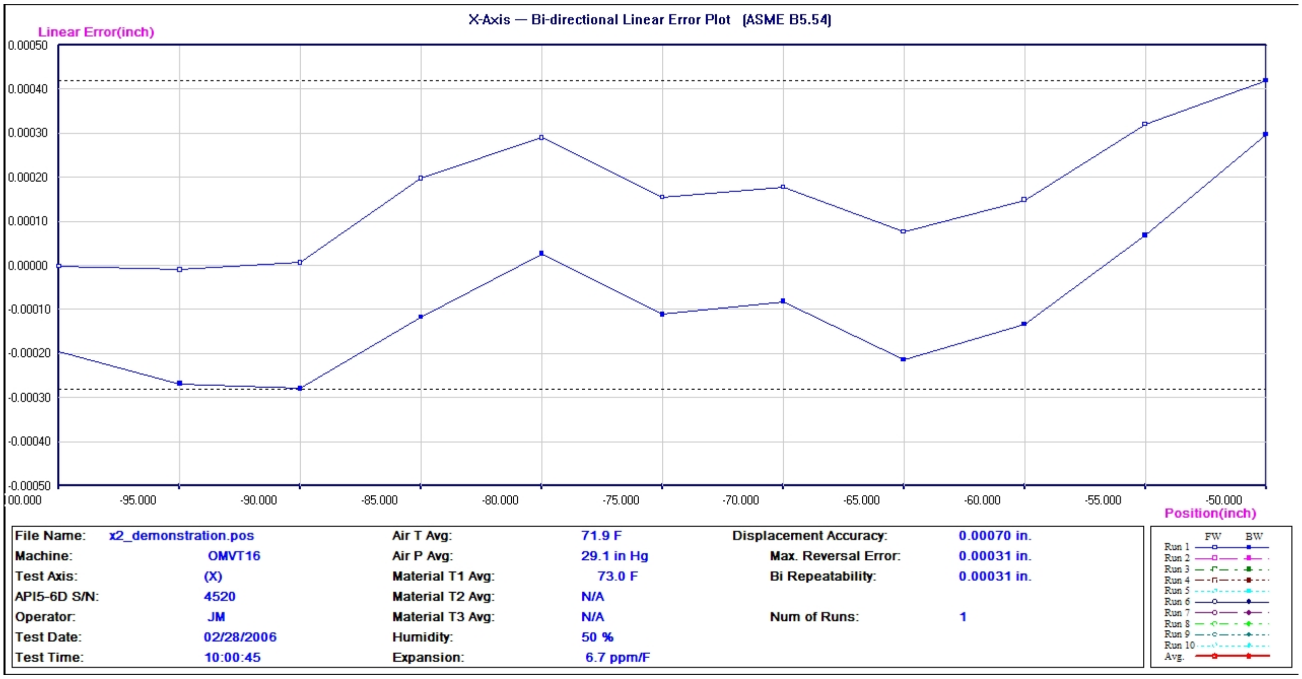
Below are some examples from an actual laser measurement done by TMI as well as the results of a rotary axis measurement. For proprietary reasons, the company names are not included on any of the plots.

Linear Compensation, Pre and Post Compensation Comparison

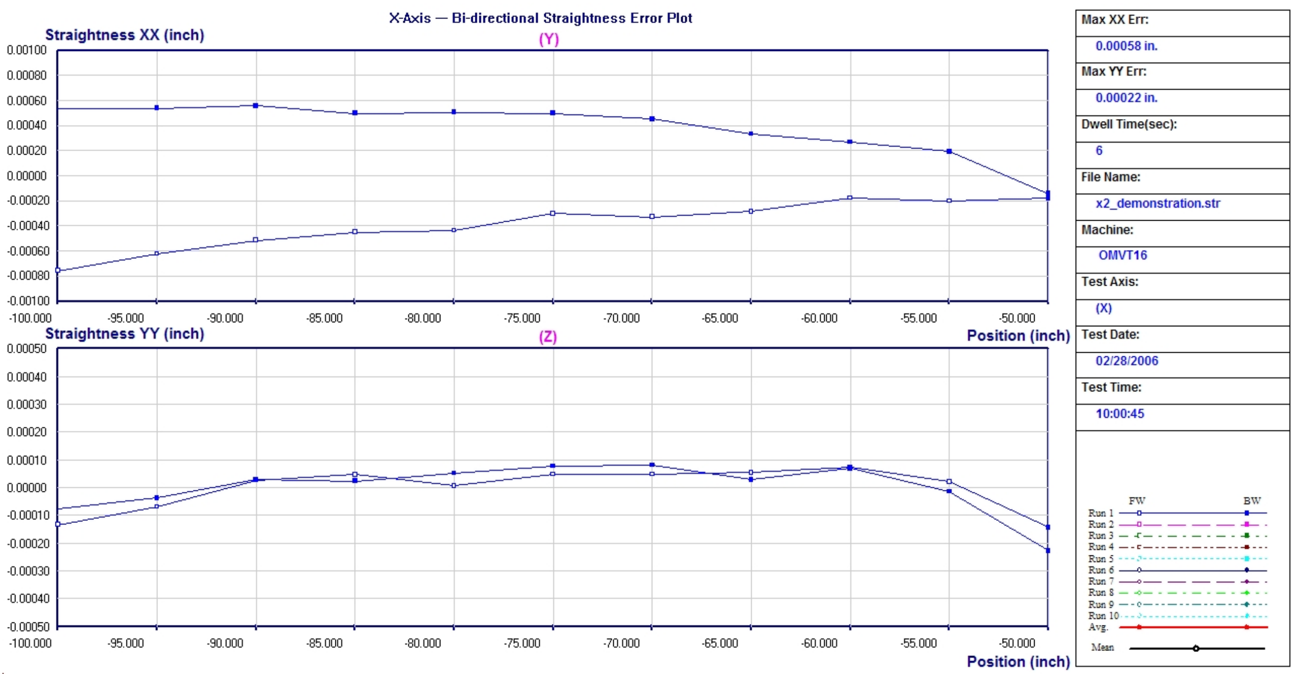
The illustration above shows a comparison of an axis' linear positioning capabilities before and after compensation. This demonstrates an almost 95% improvement in error as it relates to static positioning.

Linear, Straightness, and Angular Error

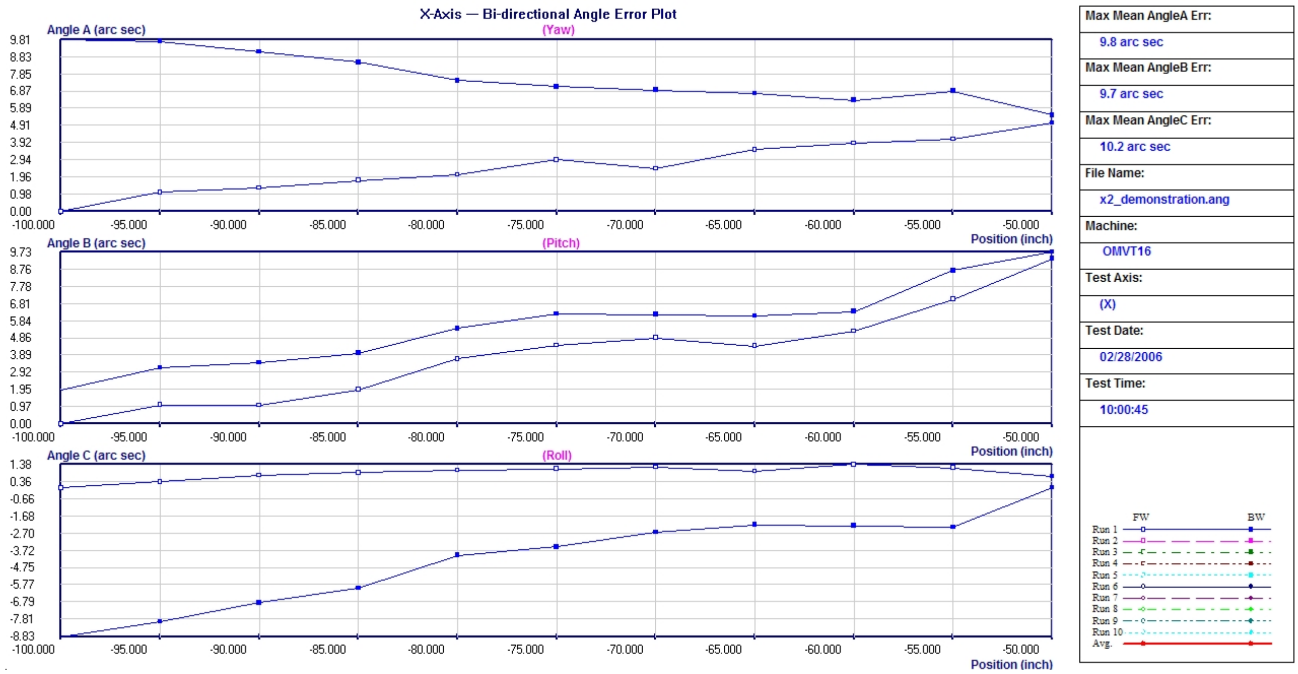
The basis for the previously shown graph is shown on the following page. When the laser is deployed on an axis, the result is three sets of graphs depicting the geometric error. Note that TMI deploys an XD Laser from Automated Precision which is the only laser of its kind that allows the gathering of this data simultaneously in a single run. While this data may be obtained with other systems, it will take a minimum of 5 setups and three runs per setup to obtain it.



The graph above depicts linear error. Notice the separation between the two curves (forward and backward directions) indicating reversal error (backlash).



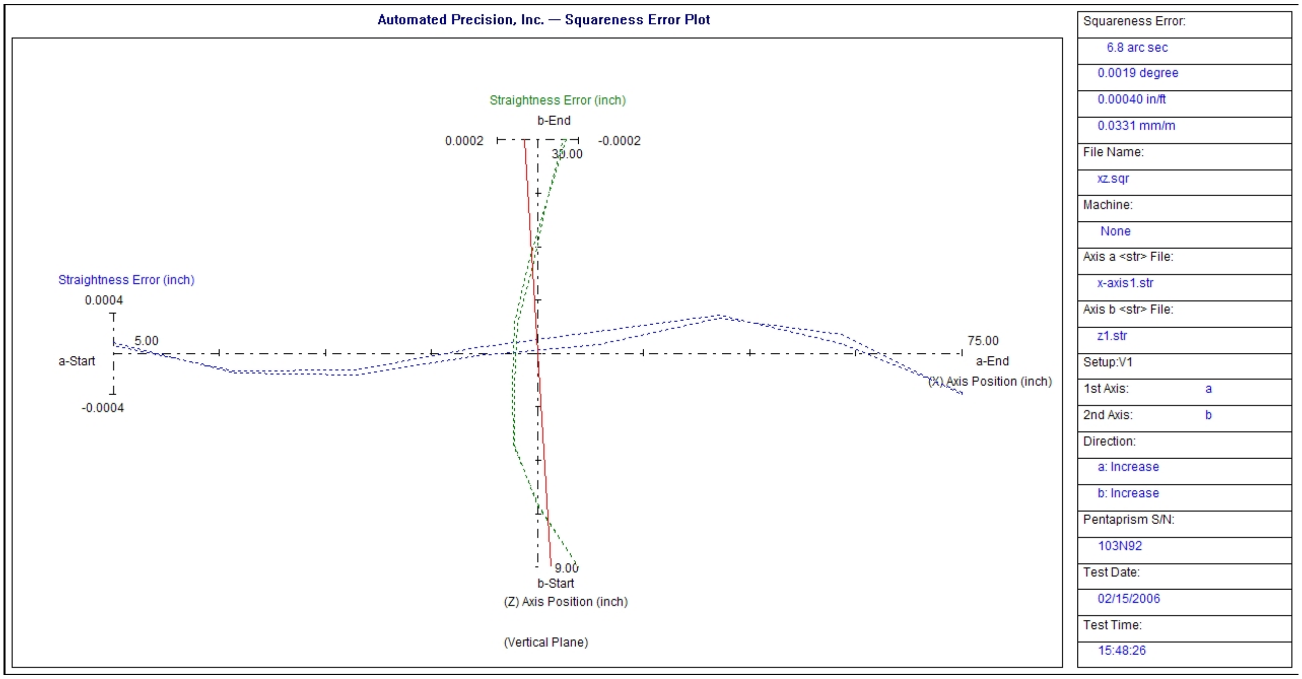
Above, are the lateral and vertical straightness graphs of the machine (top and bottom respectively). The pointed aspect of the upper graph indicates that the ballscrew itself may not be properly aligned and could be in a bind.



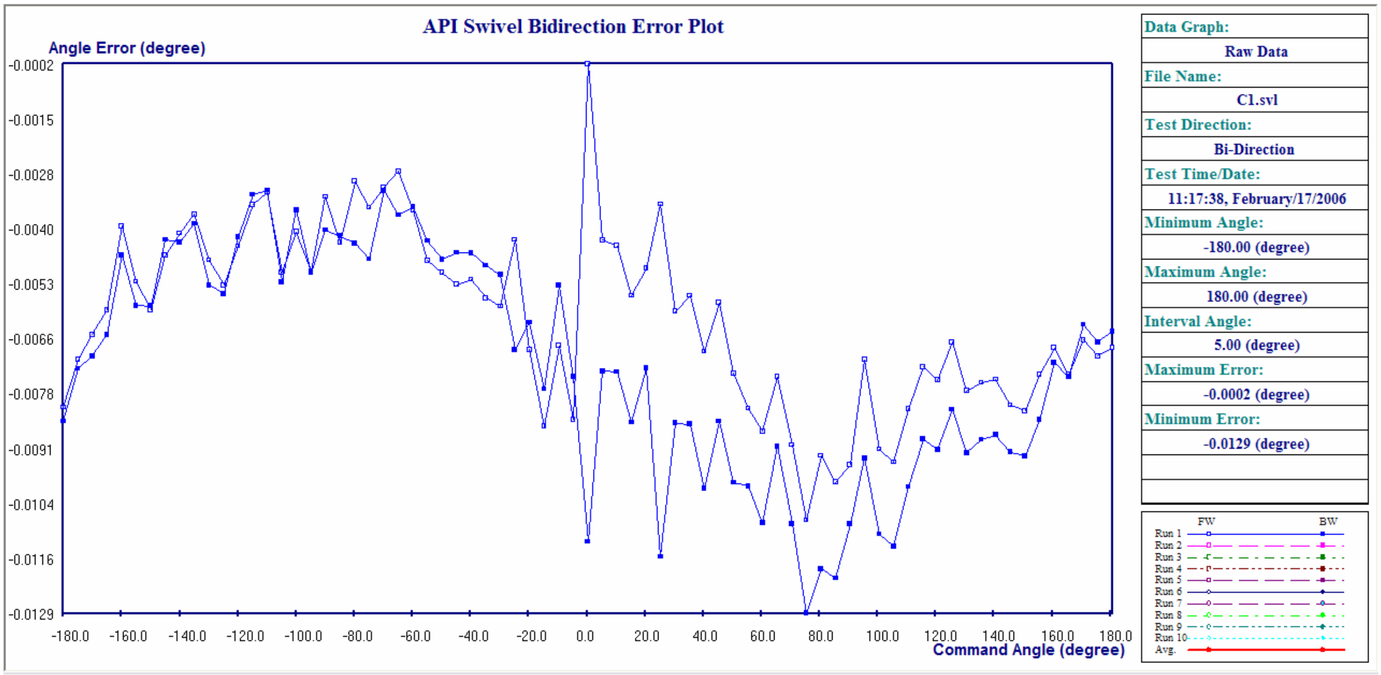
Above the yaw, pitch, and roll is shown depicting the angular deviations of the axis. Notice how the yaw and roll follow a similar pattern to the lateral straightness shown previously.

Measurement of Squareness

Due to the unique ability of the XD laser to measure all six degrees of freedom of error simultaneously, it is also possible to measure the squareness between two axes making for an almost infinitely variable electronic square. A sample of this measurement is shown below.



Rotary Positioning Performance



Shown above is a graph that depicts the rotary positioning aspects of a C-Axis. TMI utilizes an API SwivelCheck product that is accurate to plus or minus one second. Notice the separation between the curves indicating backlash in the axis. Further, notice that it is not consistent between the positive and negative angles. This axis would ultimately be compensated utilizing bi-directional compensation.

Summary

Today's high performing, highly utilized manufacturing operations are leveraging the technology described here with great success. They are realizing lower scrap rates, less rework, and an increasing customer base as they continue to be recognized for their excellence in there areas of expertise.

We at TMI certainly hope you have found value and insight within the pages of this document. The deployment of a laser measurement system to calibrate CNC machines is commonplace in many industries and is becoming more so thanks to an ever expanding familiarity with the processes, equipment, and operational advantages of doing so.

TMI is in the unique position of both selling these instruments and also performing services with them. This gives us the ability to provide consultation from direct, technical experience that translates into customer results. TMI looks forward to the opportunity to demonstrate our proficiency in your operation.