Dec 12, 2008

The Boeing Company:
ATTN: Eric Gunstone,

**SUBJECT**: Interim report on the set-point block project (senior design project)

We would like to thank the Boeing Company for the opportunity to help create a better design for the current set-point block being used in facilities throughout Boeing’s manufacturing facilities.

The following interim report is to demonstrate the ideas and directions that we have investigated thus far. We have reached conclusions based on design reviews and data from testing that will allow us to move forward with product prototyping next semester. We look forward to delivering a quality prototype and continued partnership with the Boeing Company next semester.

Sincerely,

Nathan A. Thomas

Idaho Metrology Equipment
Executive Summary

Through partnership with the Boeing Company, the University of Idaho senior design team, I.M.E., is currently helping with the development of a new set-point block which Boeing machinists use to set the height of the z-axis on their mills. The current set-point block is associated with several design limitations which hinder the machinist’s ability to accurately set the zero point of the cutting tool. The currently used set-point block also causes damage to cutters due to binding in the plunger. The set-point block can also become damaged from mill spindle over-travel when the machinist is lowering the cutter to set its height. Creating a new design that addresses these issues would provide an increase in productivity and help lower costs associated with tool replacement and materials.
**Background**

During a 2008 summer internship at The Boeing Company in Fredrickson, WA, it was discovered that the current set-point block, which is used to set the zero point on the z-axis of the milling machines, has several areas in need of improvement. The current block is used by many machinists throughout Boeing’s manufacturing facilities in Washington’s Puget Sound area. Improvements to the set-point block could help with the accuracy of machined parts, cut down on time spent reworking machined parts, reduce damage being caused to carbide cutters, and reduce damage being caused to the set-point block itself.

It was suggested that a university of Idaho senior design team be formed to test and improve the current set-point block design through a partnership with the Skin and Spar facility in Frederickson. The team I.M.E. (Idaho metrology equipment) was formed for the fall semester, 2008, and will continue to work on the project until May, 2009. I.M.E. expects to improve several problem areas associated with the current set-point block by increasing the set-point blocks visibility and usability which will be discussed in detail in the following sections.
**Problem Definition**

The current set-point block in use in Boeing manufacturing facilities has several areas in which I.M.E. can improve its performance. One of the most important issues concerning the current design is the binding in the plunger that occurs when it is subjected to an eccentric load, like the load caused by the tapered profile of a cutter (Fig.1). This binding can cause the sharp carbide cutter edges to chip against the hardened steel plunger surface. We have quantifiably measured the smoothness of plunger travel for comparison against any new designs that we create.

![Fig 1](image)

Cutter damage would also be less likely if there exists a mechanism that would allow the plunger to be depressed before the set-point block is slid under the cutter, therefore avoiding a portion of the side loading (eccentricity) experienced by the plunger. The mechanism would then be released, raising the plunger to meet the cutter once the set-point block is properly positioned.
The small dial makes the current design difficult to read, especially in low light areas, such as under the vacuum shroud on most plate mills. A method of lighting the face of the set-point block is a desirable upgrade. Also, if the cutter height is not accurately set, the parts may encounter cutter mismatch where reworking (sanding) of the parts is necessary.

The damage being caused to the set-point block itself is due to its limited plunger travel. If the machine operator accidently lowers the spindle too far and overshoots the desired distance needed to correctly set the cutter height, the plunger bottoms out and the block is subsequently crushed by the cutter. This damages both the cutter and the set-point block.

A breakdown of design criteria is shown below.

<table>
<thead>
<tr>
<th>NEEDS</th>
<th>WANTS</th>
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<tbody>
<tr>
<td>• Plunger must not bind when placed under a tapered cutter.</td>
<td>• Readable in low light situations.</td>
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<tr>
<td>• Plunger must not bind due to eccentric loading.</td>
<td>• Replaceable components.</td>
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<tr>
<td>• Plunger must not contact the cutter when being placed under spindle.</td>
<td>• Similar size and weight to current setpoint block in use.</td>
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<td>• Indicator needs a resolution of at least .001</td>
<td>• Eliminate parallaxes error.</td>
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<td>• Device needs an overall accuracy of +/- .0005 over a range of .01</td>
<td>• Similar cost to current setpoint block ($500-$1500)</td>
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<td></td>
<td>• Keep chips and debris from contaminating plunger.</td>
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<td></td>
<td>• Easy access to replaceable batteries.</td>
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<td>• ½ inch of plunger travel (.100 above 2.100 and .400 below)</td>
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**Project Plan**

**Second Semester Development Timeline**

The team plans on continuing to develop the concepts formed during the last design review over the winter break. We will have several ideas ready to analyze as a team and choose a direction that appears to yield the best candidate for prototyping.

**Concepts Considered**

Many concepts have been generated in an attempt to manipulate the space we are allotted and meet the specification requested. All design concepts have five key driving factors (picked from the specifications) which are: digital display, keep all measurement related values to .0001 inches, give a full half inch of travel, run smoothly, and of course be as small as possible. All other requirements are considered possible if the first five are met.
Concepts were generated from group discussion, internet research and outside opinion – a large majority of these came from the Universities master machinist, Russ Porter. Our ideas ranged from using lasers, hydraulics, Hall Effect devices, linkages to rack and pinion systems, linear encoders, 45° wedges, and off the shelf dial indicators.

Technology researches that supported our initial efforts and spawned new trains of thought were in brake systems (hydraulic), linear potentiometers, magnetic and optical tapes, many different dial indicators, rotary encoders and inductive distance sensors. As we discussed the technology and ideas we wanted to keep the building process simple and focused on ideas that would allow an easily machined base that would accept a dial indicator with few modifications. What follows is an overview of all the ideas, technology, its advantages and disadvantages.

No contact tool sensing
This was one of the original ideas we discussed. It involved using techniques that required no contact with the tooling to accomplish tag-off. The idea was to use lasers, sonic, optical or inductance to sense where the tool was located. We even considered attaching this to the machine control and letting it tag-off itself. Researching the idea we quickly found a host of devices that do just this. One example is the Renishaw NC4 which is used for both tag-off and broken cutter detection. It was learned that the mills currently have a similar system already in place along with a touch probe. Both systems have been disabled due to inaccuracy and not being preferred by the machinist; they like
a more hands on approach where they can see a measurement with their own eyes. Upon learning this information, we knew only a set block would work.

**Hydraulic**

The concept of using hydraulics was thought of independently by two team members. The beauty of this idea was to change the direction of force from vertical to any angle that suited us and get a full half inch of motion from the plunger. System design included a pressurized reservoir and two chambers; one chamber would be to take measurements while the other would allow for pressure release in an over-travel event. A spring in each chamber would have a different spring constant so that the measurements chamber would not be influenced by over-pressure chamber. Measurements could either be taken by direct displacement and a dial indicator or by calibrating a pressure sensor. The problems were the tight tolerance all the bores would need to be machined to (to prevent leaking), possibility of leakage, possibility of low accuracy, labor intensive yearly calibration, difficulty calibrating a sensor pressure if it was use, and an increase in block size. A hydraulic block would have more plunger travel but would likely increase in width or length.

**Linkages**

Linkages were discussed briefly on several occasions but were never seriously considered due to the tight tolerances that would be required by the mechanism and lack of faith in linkage accuracy. The possibilities here include multiple bar linkages or cam mechanisms. Another problem we were encountering, similar to the hydraulic block, was
if a digital dial indicator was used the indicators size dictated the block size; unless the linkage allowed attachment of the indicator to the plunger in a vertical orientation (like the current block) the set block’s length would significantly increase.

The Caliper Idea

A pair of digital calipers gave us this idea. If we could mount the floating jaw of a digital caliper to the plunger and the fixed jaw to the base we could cut off the extra scale length and have an easily manufactured set block. From this idea, we started researching magnetic tapes, optical tapes and glass slides. Both magnetic tape and optical tape work on the same general principle. Microscopic tick marks in the tape are measured by a reader head. The tape has to be long enough that over the full range of travel a portion of the tape is always under the reader’s sensor; this can range from 10 to 25 millimeters in addition to the measurement length depending on the manufacturer. Glass scales work in a similar manner but have greater accuracy. We found that the 543-253B Mitutoyo Dial indicator has a glass scale inside it. Research turned up many companies that make magnetic or optical tape. This would be the ideal setup because the tape could easily be cut and mounted on the plunger. The reader would go into the set block and measure plunger movement. The company Micro E Systems makes one of the smaller sensors; their M-1500H uses a glass scale that is .709 inches long and mates with a reader that is .810 inches long for a total measurement range is .512 inches. This is exactly what we are looking for, but it is made to use with a computer. It relays data and power using a 10 pin cable and operates at 5 volts DC and 60 milliamps. To use this system we would have to make our own display and processing circuitry. The entire package would need to fit
inside the block along with the batteries to power it. The majority of companies manufacturing tapes and scales all have sensors that run on 5 volts and attach to a computer or separate (and rather large) display unit.

**Caliper Idea Spin-off**

When first discussing the caliper idea we were not sure magnetic tape could be cut. If it could not be was there another method of making calipers work. We came up with the idea (temporarily setting aside our digital pursuits) of using analog dial calipers. They work on a rack and pinion system which could transmit the linear movement into rotational. We could likely fit a set of dial caliper in the required space, cutting off the excess scale length, but it was not a digital solution. Prior to abandoning the idea, research on magnetic tape turned up a similar product – the rotary encoder. These encoders work on the same principle as magnetic tape or optical tape. The fact that they rotate makes them able to continuously measure a length. Connecting them to the rack and pinion system provides a compact set block. Micro E Systems makes a rotary encoder that is about the same size as dime, but they use the same reader head as the linear tapes and have the same problems.

**Inductive Sensors**

Inductive sensors come in many shapes and sizes but all operate using the same basic principle. Induce a magnetic field and measure how it interacts with nearby metal – similar to a metal detector. The three main types found during research were: a magnetic ring fit over a rod and able to slide up or down it, a plunger able to slide into a base unit,
or a proximity distance induction sensor. The first type measures the distance the magnet is from a base unit and the second type measures the distance the plunger is inserted into the base unit. Both these systems are accurate and made to measure distances as small as half an inch of travel, but the base unit of each brings the total system length over 2 inches. The proximity distance sensor can tell the distance to a piece of metal without touching it. Balluff produces several inductive distance sensors, one of which has the correct dimensions to fit inside a set block and measures up to a distance of 60 mm. It could easily measure the distance the set block plunger is depressed. The problems with it are repeat accuracy of .0002 and 24 volt DC with 20 milliamp power requirement. It would also require making a display and processing circuit.

**Dial Indicators**

The digital dial indicator became our best prospect for creating a new set block. They have many benefits over other methods. To begin with, they are digital and accurate. This checked off several of the specifications we were working towards. They can be bought as a single unit – having a display, a power supply, a processor and variable lengths of travel including half an inch. Disassembling a non-functional Mitutoyo 543-253B indicator, we found it would be easy to mount the unit inside a set block. The indicator turned out to be too large to mount vertically, so, we decided to lay it flat. To change the direction of the set block’s plunger motion we used a simple linkage – a 45° wedge. Research showed us that the thread tip of the indicator’s plunger could be replaced with a roller attachment but in tests even the factory installed blunt tip ran smoothly on a ground 45° surface. The face of the indicator is easily removed, being held only by an o-ring,
and could be mounted at an angle for better viewing. The only problem was overall size. The face was too large to be placed vertically, at 2.3 inches in diameter, in the block and the overall length was just over 3 inches including the room needed for the plunger to extend from the back end. This made any set block design longer than the original.

**Smoothness of travel**

To fix one of the main complaints of the old set block, plunger sticking, we researched multiple bearing and bushing possibilities. We bought two types of open linear roller bearings and were given a closed linear roller bearing and Frelon lined bushing to examine. We compared these four possibilities with a brass bushing we produce. It turned out that the Frelon lined bushing was the smoothest with little play between the shaft and bushing. A Frelon lined bushing will likely be in any final design we assemble (see appendix).

Our research into the variety of technologies available while may not be useful in our final design has given us insights into how make an easy to design and manufacture set-point block.

**Concept Selection**

The final concept selection was a result of extensive analysis of product specifications and design restrictions. The initial specifications from the customer provided a starting point from which a range of possible solutions could be investigated. These options were
compared and modified to create a design capable of fulfilling the minimum requirements.

An assortment of concepts were considered, each utilizing various technologies and methods to achieve the same end result. Each concept contained various advantages and disadvantages with its design. All concepts were compared based upon the various merits of the design. Several designs were eliminated due to the physical constraints provided. A number of concepts involved the adaptation of current production measuring devices, however many of these (digital caliper, magnetic tape) were not able to fit in the desired configuration. In addition to the height restriction, travel of the measuring device proved to be a large concern. Though many devices could provide the necessary travel they would often not have the accuracy required to meet customer specifications (as with the travel indicator). After many devices were examined and tested a digital dial indicator was selected for its travel and accuracy. The selected indicator also provided a removable face which enabled more flexibility in readout placement.

Once a measurement device was selected design geometry could then be developed. The primary challenge in this area involved the transmittal of motion from the plunger to the measuring device without adding error to the measurement. Several methods were considered including hydraulic, rotational and direct linkage connections. After careful investigation into each method a direct connection (in the form of a 45 degree slider) was selected. This method was selected for its compact size, ease of maintenance and low cost.
for manufacture. With the main components of the system selected smaller details could then be addressed.

As per the customer specifications a smooth, non binding plunger arrangement was required. In order to do this it was determined that a linear bearing or high quality bushing was needed. Initial research showed that a small open linear bearing would allow the smooth operation of the plunger while allowing the design to stay below maximum height requirements. After testing of the bearings was performed it was found that the open bearing design would not have the required tolerance. Several other bearing setups were considered including the use of two shorter, closed bearings on the top and bottom of the plunger; however this idea was discarded due to the desired sizes not being commercially available. The final concept included the selection of a Frelon lined bushing into which a slot would be machined to provide the necessary opening for the angled sensor actuator. This bushing was selected for both its high tolerance and much lower component cost.

Development of the block housing geometry was a result of manufacture focused design. The geometry associated with the housing was developed with a primary concern for keeping the design as compact as possible while also minimizing the number of machining operations to keep manufacture costs minimal.
System Architecture

The design that resulted from our work during the first semester is dictated by the need to pack a digital motion sensor and a high quality linear bearing into a minimum sized package and under a tight height restriction and still maintain the required range of travel. Getting the range of travel while using a good bearing or bushing uses up most of the height restriction and dictates that the sensor can not be placed directly under the plunger. Also, of the stock sensors available, none were both short enough to mount vertically and had the needed range of motion. These restrictions dictate that some sort linkage is needed.

The chosen design uses a ground-round rod mounted in a bushing. An angled slider surface is attached to the rod and moves a digital dial indicator mounted at a right angle to the plunger (Fig 2). This results in an elegant design for a number of reasons:

- Simple, common, proven solution for the plunger support
- By slotting the bushing, it can be almost the full height of the block
- Stock or nearly stock components for the sensor
- Only 2 moving parts
- Relativity few pieces total
- Truly linear readings.

As with the original block, the actual measuring device was chosen to be a standard item. In one of the designs, it would be mounted without modification in the block (fig 3). In
the other design, the face plate would be removed and mounted separately (it is already a nearly separate piece to allow it to rotate). In either case, this resulted in a minimum amount of labor and a total absence of high precision operations.

Fig 2

![Fig 2](image)

Fig 3

![Fig 3](image)

The improvements in the bearing are to address the issue of side loading errors (see Appendix). As a result of the very short guide surface on the existing block, the plunger could rotate sideways and jam causing both of these problems. By lengthening the guide
and switching to commercial parts, both of these issues can be mitigated or removed. A bushing was selected because the open linear ball bearings that were tried did not provide smooth enough of accurate enough support.

Regarding any concerns over wear and operational life, the design’s two moving parts provide a minimum of opportunities for this to cause problems. Outside the bushing and the internals of the indicator, the only sliding contact is the angle block. As this is a low force contact and both sides can be hardened steel, this is not expected to be a concern. All told, the block consists of a plunger head, shaft and angle block, a bushing, a push down lever, an indicator, housing, cover plates and a few miscellaneous springs and fasteners. This should result in reasonably low production and maintenance costs.

Lastly, because the slider arrangement has no rotating parts and is always under a slight uniform load, there is no built in source of non-linearity and minimal room for backlash. Without getting into custom fabricated sensors, this is likely the most compact design that fits the requirements.

**Future Work**

Our plan as of 12-12-08 is to rework the current design of the Boeing set-point block and correct as many issues concerning it as possible. We are committed to delivering an improved version and have decided to focus our time after winter break to areas we know that can be improved easily from knowledge we have gained from our previous testing.
We look forward to beginning the prototyping phase next and plan on having concepts prepared for prototyping shortly after returning from winter break.
Appendix

Here we show a quantifiable measurement of the smoothness of travel for the currently used set-point block. This data will be used for comparison to new designs.

Center and plunger edge eccentricity testing
Rendered photo of angled block design

From left to right: stainless open bearing, stainless closed bearing, nylon open bearing, brass bushing, and Frelon lined aluminum bushing.