Design of Mechanical Testing Device to Measure Break Angle of Thin, Stainless Steel

by

Stephen Weiner

Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of

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Abstract

Working with Gillette Corporation, an automated mechanical testing tool that bent a small flat piece of steel was designed. The design of the tool was an effort to improve upon previous generations of the same tool. It consisted of three main elements; a servomotor, connected to a torque transducer, which was connected to a break device. A thin piece of steel was loaded into the break device and the motor was activated, moving a flipper arm on the device which bent the steel. While bending this piece of steel, the torque transducer would relay torque and angle information to a computer. This information was collected and displayed in Excel as torque versus angle plots, which would show the moment at which the piece of steel was broken. This entire process was automated so that after loading the steel, one click of a button would run one test. Razorblades were primarily bent with the device until they would break, and for this reason, the measuring tool was called the 'blade break test.' The work consisted of designing a robust mechanical system coupling the three devices mentioned above in series. Code was written in Visual Basic that managed all the individual devices in the measuring tool, getting them to work together and linking them with a computer. A user interface was designed with engineers in mind, imbedding automated data collection and representation through Excel. Finally, a manual was created accompanying the device so other engineers could use, troubleshoot, and modify the 'break test.' The result of this project was the creation of a successful measuring instrument with full documentation and functionality.

Thesis Supervisor: Ernesto Blanco

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Introduction

At Gillette Corporation, three previous generations of steel break tests were created, each design adding improvements to the previous. The main goal of the devices was to bend a small rectangular piece of steel until fracture, while measuring the torque felt by the bending arm and the angle of the bend. These two data sets, torque and angle, plotted against each other delivered a curve showing the torque and angle until fracture occurred. Naturally, as the bend angle increased so too did the torque, until fracture; when the torque dropped to zero, there was no more resistance from the steel.

The bending was done in a specially designed break device seen on the right in Figure 1. The measurement of angle and torque was automated so that while a motor bent the steel in the device, a sensor would relay positional and torque data. The current generation design addressed some of the shortcomings of the previous designs, and is three years along from the initial concept of creating a break test device. More parameters, such as position of the bend on the piece of steel, are now adjustable. Also, air cylinders were added to automate the operation of the clamping device to hold the steel previous to

Figure 1: Previous Generation versus Current Generation Break Device

bending. The goal of this project was to incorporate this new break device with a new complete measuring package. Figure 1 shows an older version of the break device that was used versus the current one. One can see the added micrometer and air cylinder on the newer model. The new generation break device had two micrometers that adjusted the position of clamping and the position of bending. This meant that any position on the piece of steel being tested could be targeted for a bend.

Razor blades, used in most of Gillette products, were the main thin steel tested. Gillette is the leading manufacturer of male and female shaving implements, outputting thousands of products each day in factories all over the world. In any company committed to creating the best possible product, quality testing and assurance is an important part of the operation. Figure 2 shows the typical razor blade prior to final processing and placement within a Gillette product. Blades of this size and shape were tested with the measuring device.

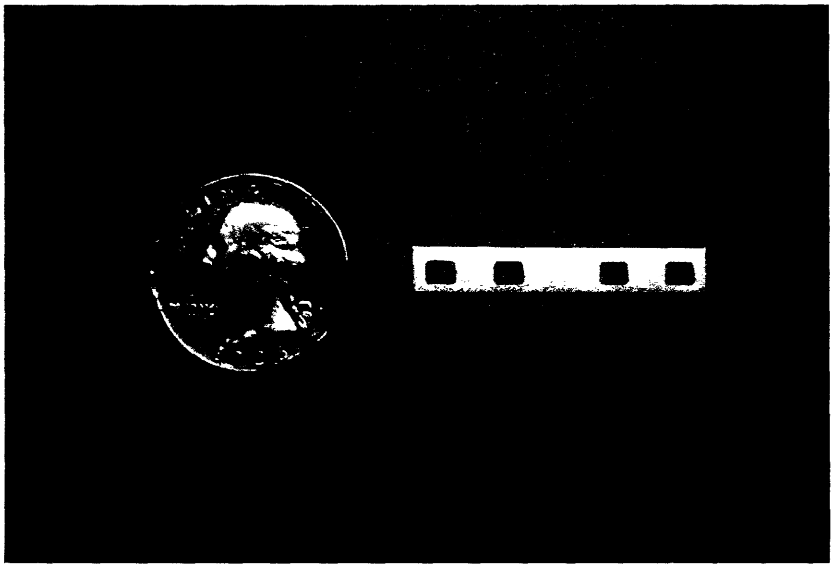


Figure 2: Thin Steel – Gillette Razor Blade

Previous generations of these measuring devices have been used at Gillette to test blades of varying treatment and design. The devices are most useful as relative measuring instruments, comparing two blades or pieces of steel to each other. Pieces of steel with different heat treatments, for example, will bend and break differently. Different products could require different properties and processes that could be tested with this measuring device. They were also valuable as general structural integrity tests, comparing the latest generation of blade to previous generations, or searching for inconsistencies in a blade design leading to premature failure.

The software that controlled previous devices was robust but inflexible. TestPoint software was previously used to control the sensor and motor. TestPoint also gathered the data from these devices. In the current project, Visual Basic rather than TestPoint, was used in the current project to control these devices. Visual Basic is a programming language in which an interface is created first, and then functionality is added to that interface. The Visual Basic framework allows no limitations in the design of the final program created, as opposed to the rigidity of TestPoint. A simple interface with adjustable parameters such as velocity, acceleration, and angle of rotation was created that could run a successful test with only a few mouse clicks. In previous generations a graph would be generated in TestPoint software while the current software outputted the data and a graph to Microsoft Excel. Integration with Microsoft software was an important product requirement, so that an engineer could easily export a graph to a slide show, for instance.

Theory

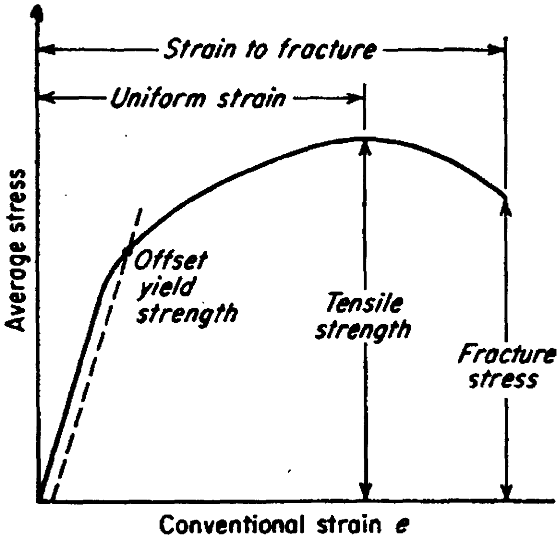
It was important in this project to understand how the steel tested was expected to react to the severe stress we placed it under. This was done using simple stress strain curves learned in the classroom and FEA computer testing.

The Structure of Metals

The crystalline structure of a particular metal determines many of its properties and behaviors. Other factors that determine a metals behavior include its composition, presence of defects, grain size, grain boundaries, environment, and surface condition of the metal. Alloying a metal is the process in which atoms of some other metal or metals are inserted within the crystal lattice of another metal. This often improves the properties of the metal. Steel is an alloy of iron with carbon molecules. The proportion of carbon present can easily and cheaply be modified, greatly affect the properties of the steel, producing chromalloy, for example, a very useful steel known for its high tensile strength and hardness.

The exact percentage of carbon and preparation steps used in creating a Gillette razorblade is a highly guarded secret so they will not appear in this report. It is obvious though, that the blades are stainless steel, containing carbon, chromium, and possibly other alloying elements. Stainless steels can make great cutting edges because they undergo passivation, a reaction between oxygen and the chromium in the steel that forms a thin layer of chromium oxide around the steel, protecting it from corrosion. The higher the carbon content of the steel the lower the resistance to corrosion though, because the carbon acts as an inhibitor, reacting with the chromium rather than allowing the chromium to react with oxygen.

It was expected that most of the steel razor blades tested would undergo brittle fracture if they failed. This assumption was made because of how thin the steel was resisting the bend, and how extreme the angles of bend were. Depending on the location in the bend of the steel and the rate of the stress induced, it was also expected that some ductile failure would occur before brittle fracture. It was expected that the steel would deform plastically in some cases, before it fractured. Figure 3 shows a general stress curve based on the material properties of the steel. While not perfectly applicable to the situation of steel in the break device, it was still a good indication of the behavior one might see; elastic to plastic to failure.



.**Figure 3: Stress Strain Curve of Steel***

Mechanically, it was assumed that the steel used had the properties of Martensitic 440 Series. Martensitic 440 contains high chromium content, as high as 18%, and no nickel. These steels have high strength, hardness, fatigue resistance, and moderate corrosion resistance. Martensitic stainless steels are primarily used for cutlery, surgical tools, or springs.

Table 1: Martensitic 440 Steel Properties

Ultimate Tensile Strength (Mpa)	480-520
Yield Strength (Mpa)	210-290
Elongation in 50 mm(%)	35-25

FEA Testing

Because small displacement assumptions could not be made concerning the bending of the steel, Finite Element Analysis software was used to predict how the steel would bend and break. A thin piece of rectangular steel was modeled and fixed according to the design of the current generation break device. Then, torque in the appropriate location was applied to the steel to get an idea of how it would bend and break.

The steel used by Gillette undergoes various treatments that ensure uniformity so it was expected that the FEA results would be fairly accurate. A deformity in a piece of steel can be a location of concentrated stress and strain leading to early failure. No such deformities were present in the modeled steel. The numbers from Table 1 were used in the model, with an average of the high and low values being used when needed.

Solidworks and Cosmos software was used in this test. Based on the FEA results, it was confirmed that a flat piece of Martensitic stainless steel of realistic razor blade dimensions, fixed as a cantilever, with a uniform pressure of 2 psi would deform to approximately 30 degrees before fracturing at the location where the steel was fixed. In Figure 4 we can see that the stress concentration in the steel is located at the bottom of the piece, the fixed edge, the eventual site of fracture.

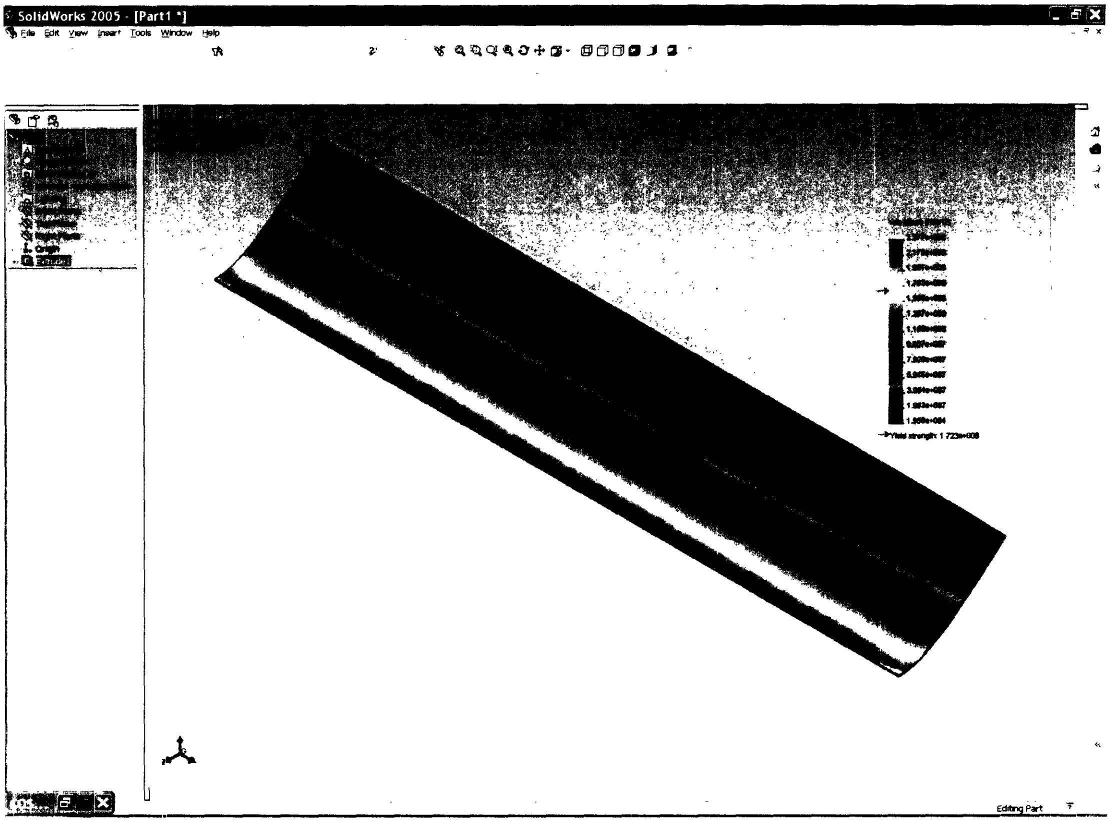
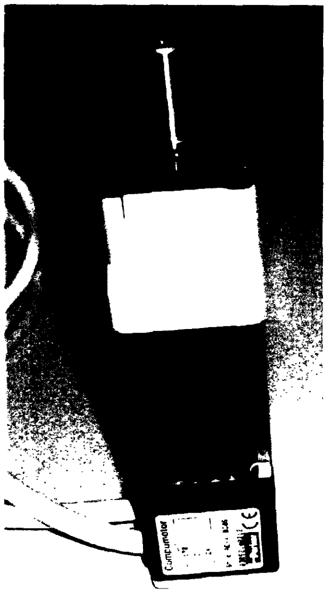


Figure 4: Cosmos FEA Testing

Materials

Parker Gemini Motor – Model SM161AE (Modified with 5.5:1 Gear Ratio)



A servomotor was used to turn the flipper arm of the break device, the main force in bending. The motor was rated for a peak torque of 4.9 in-lbs and a continuous stall torque of 1.6 in-lbs. A peak torque of no more than 2 in-lbs was expected based on FEA, well within the range of the motor. The motor was coupled with the ComGemini GV6 Servo Controller, which was in turn interfaced with the computer. Visual Basic was used to issue commands to the servo and motor. A special library of Active X controls was used, allowing for easy interface through Visual Basic.

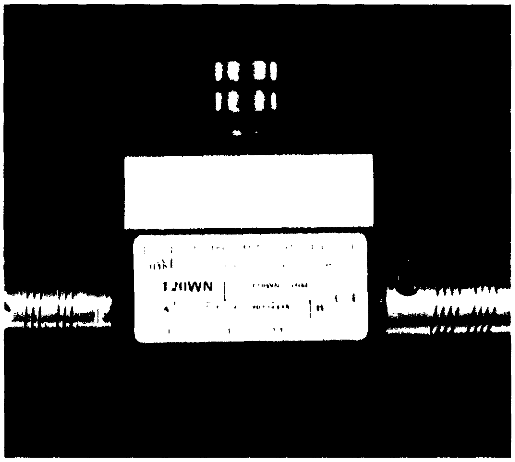
This motor was mounted horizontally using two mounts machined from aluminum, constraining the motor in two spots. It was mounted on an aluminum plate and positioned to the right of the torque sensor.

ComGemini GV6 Servo Controller

The motor was controlled using this electronic controller. This controller offered basic motion control and programmed movement capabilities. It also had an input/output drive that allowed connection the GEM VM-50, a 50 pin drive, from which was drawn positional data.

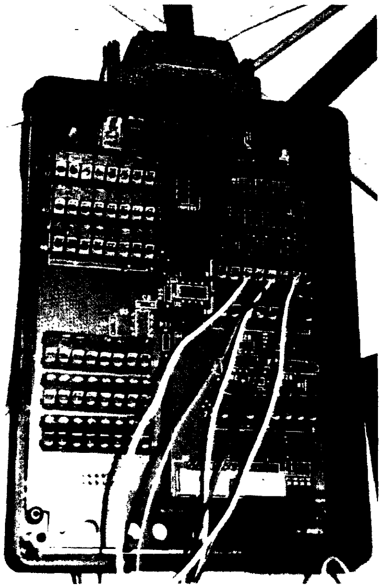
To confirm that the controller and motor were wired properly, Motion Control software was used. This software was bundled with the motor and allowed control of the motor through a text based interface. Typed commands were executed immediately by the motor.

Torque Transducer with VK20 Terminal Box (HBM – T20WN Model)



This rotary torque sensor was rated at 8.8 in-lbs. The maximum value expected based on previous generations of the device was for a piece of steel .003 inches thick was 2 in-lbs. The sensor was mounted with a piece of aluminum and set screws. It was placed in between the motor and blade break device, with the measurement side facing the device.

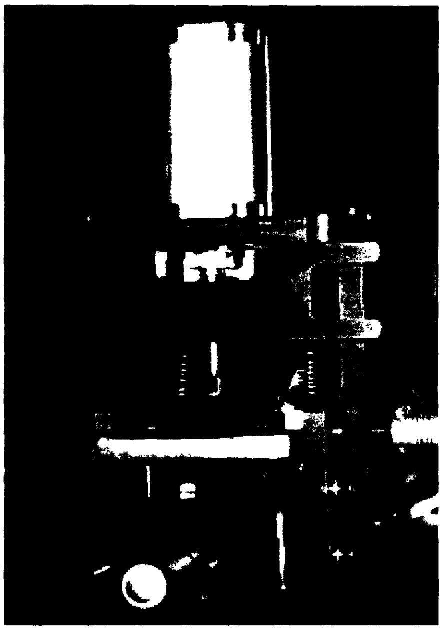
Data Acquisition Board - Data Translation DT304 Series



A data acquisition board was used to collect data in the form of voltage from both the torque sensor and motor. The motor relayed positional data through the GEM VM-50 while the torque sensor relayed torque data. The board was configured for continuous, differential sampling, each channel having its own ground. Two channels were used, one for positional data, one for torque data. The board had a total of eight channels for differential sampling so more measurements could have been taken.

Housing for the board was machined from a plastic enclosure box. Rectangular holes were milled at the top and bottom for the computer connection and sensor wiring. It is pictured here without the lid.

Steel Break Device



Gillette engineers designed this machine previous to this project. The device was machined from steel and aluminum parts, and weighed approximately ten pounds. It clamped down a piece of steel with an air cylinder driven piston, and then bent this piece of steel using a rotating flipper arm. The motor was mounted in line with the axis of the flipper arm. The position of the bending on the piece of steel was fully adjustable using two micrometers mounted on the device, one in the front seen here, the other in the back, not pictured. It was mounted to the left of the torque sensor, putting the three main devices in series.

In its current state, the device's air cylinder was not attached so a bolt was used to hold down the clamping arm, pictured here.

Results

Figures 5, 6, and 7 show the completed measuring device. The motor, sensor, and break device were aligned in series, mounted on an aluminum plate, and connected with flexible, torque-transmitting couplers. The couplers were special ordered from McMaster-Carr to fit the shaft radiuses of all devices.

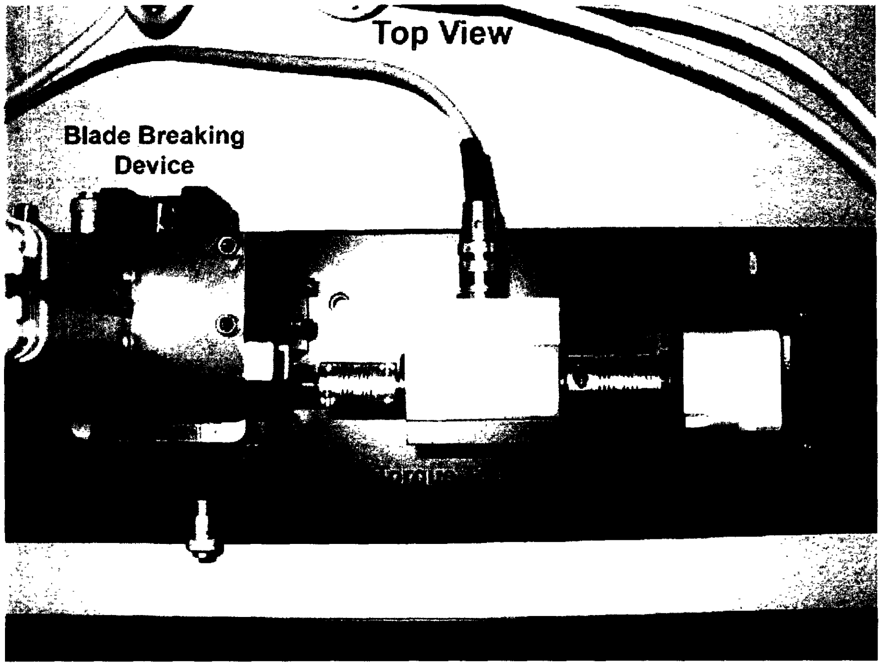


Figure 5: Completed Break Test Device (Top View)

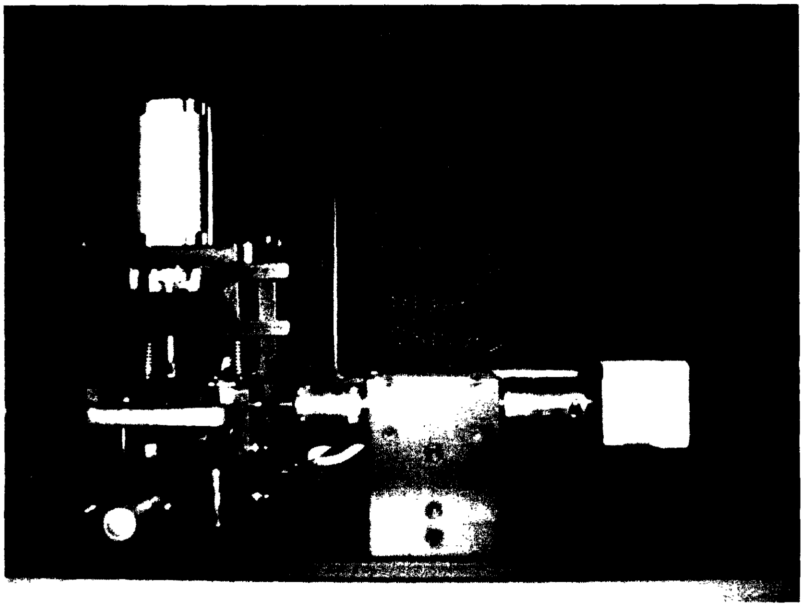


Figure 6: Completed Break Test Device (Side View)

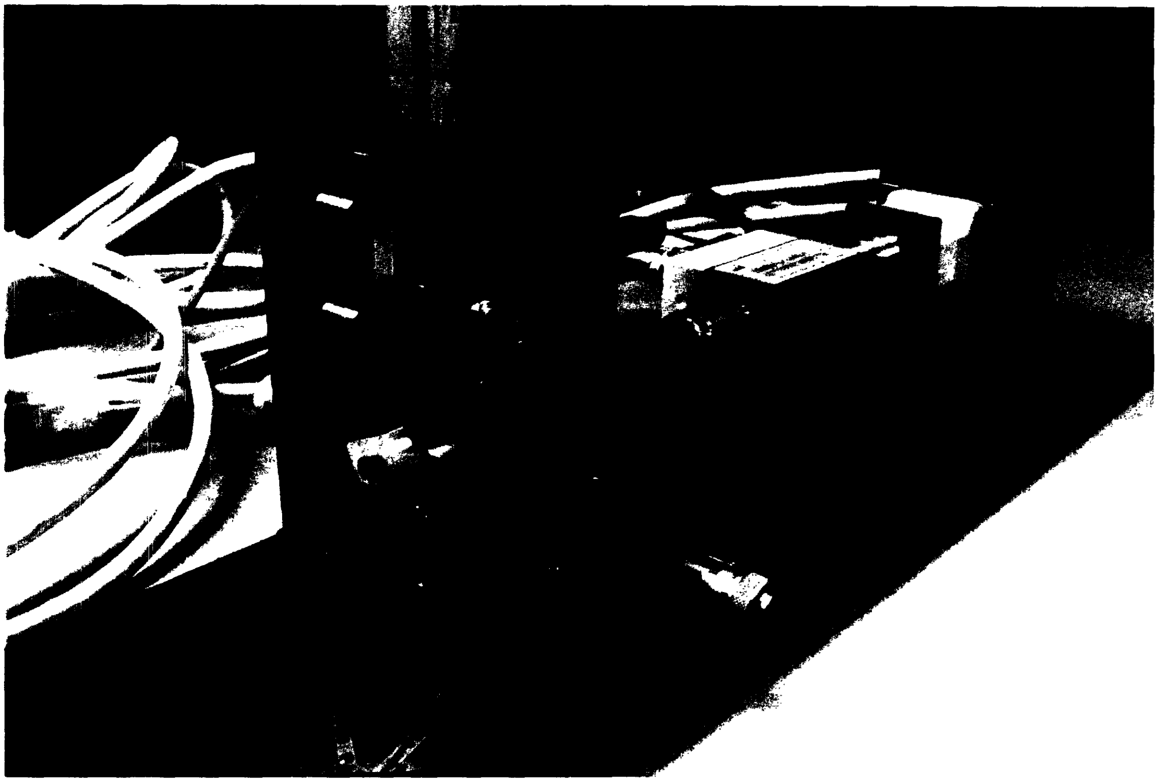
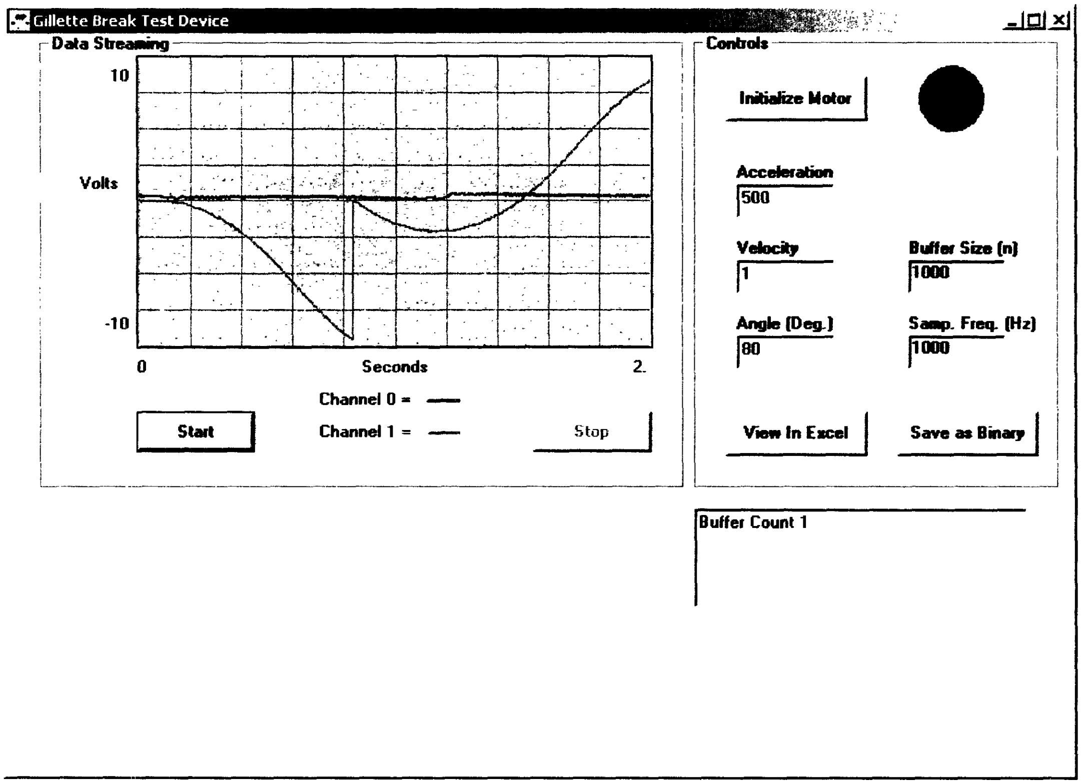


Figure 7: Completed Break Test Device with Flipper Arm at 45° (Isometric View)

In order to ensure that the devices would be lined up perfectly, the drill locations of the holes in the plate were predetermined and milled with the aid of a digital measurement readout. Any offset was further eliminated by the linear displacement couplers.

After aligning and mounting the devices, software had to be written to control them. Figure 8 shows the computer interface created in Visual Basic. The design parameters were functionality and intuitiveness. The user initializes the motor then begins a test, once the appropriate parameters have been entered. The user may adjust the velocity, acceleration, and final angle traveled to by the flipper arm. The user starts and stops the sampling, by clicking 'start' and 'stop', when the desired number of data sets have been taken. The graph in the interface shows the results taken from the data board in voltage, showing the user that data is being taken. In addition, the text box in the bottom-right informs the user to the number of buffers of data that have been taken, so that the user may stop sampling data when appropriate. Once a test was completed, the user could save his data to a binary file, saving space, and then later recalling that file for plotting. If they wanted to immediately plot their data, they could click, 'Export to Excel', sending the data to Excel in appropriately labeled columns where the user could then create a plot.



Acceleration 500

Velocity 1

Angle (Deg.) 80

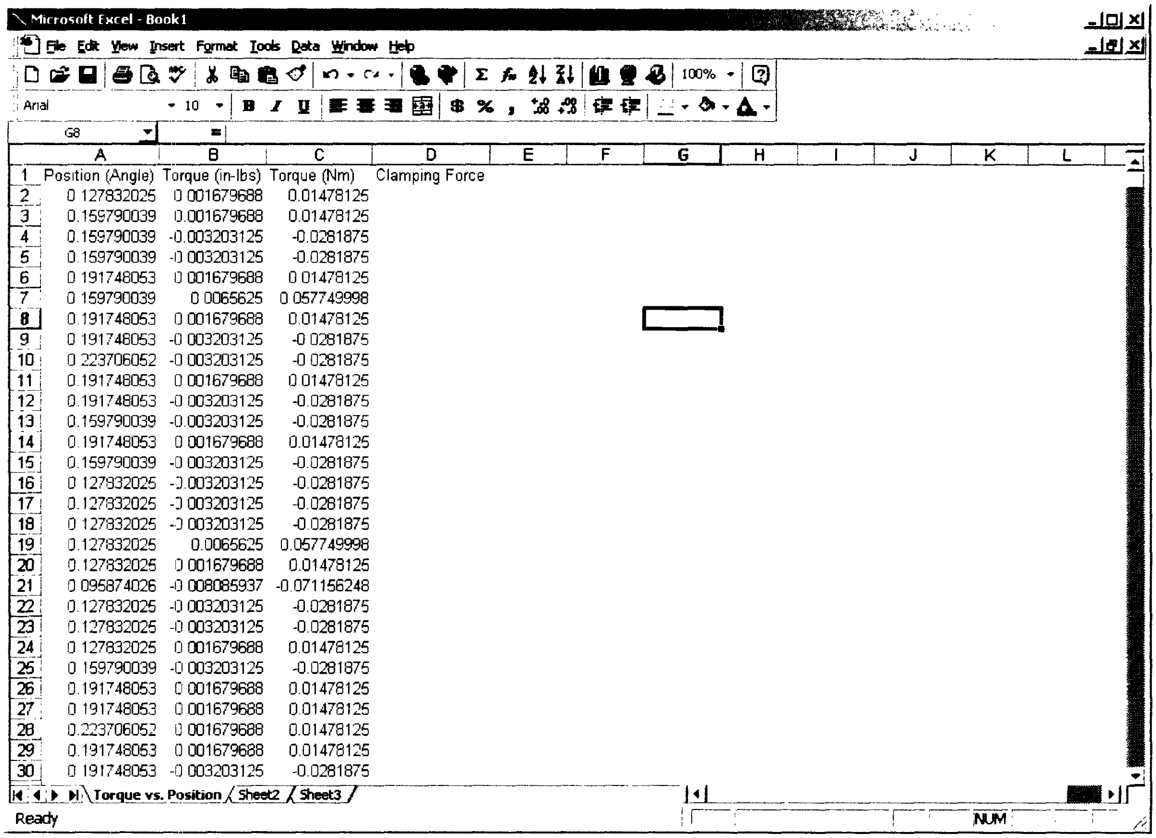
Buffer Size (n) 1000

Samp. Freq. (Hz) 1000

Buffer Count 1

Figure 8: Visual Basic Computer Interface

Figure 9 shows typical data output from one run of the device. Upon clicking "Export to Excel" from the Visual Basic interface, this spreadsheet was generated containing positional data and two forms, English and metric, of torque data from the latest run. Clamping force data was not yet generated because the air cylinder and additional sensor were not installed. These extra devices would have measured the force of the clamping arm on the piece of steel.



	A	B	C	D
1	Position (Angle)	Torque (in-lbs)	Torque (Nm)	Clamping Force
2	0.127832025	0.001679688	0.01478125	
3	0.159790039	0.001679688	0.01478125	
4	0.159790039	-0.003203125	-0.0281875	
5	0.159790039	-0.003203125	-0.0281875	
6	0.191748053	0.001679688	0.01478125	
7	0.159790039	0.0065625	0.057749998	
8	0.191748053	0.001679688	0.01478125	
9	0.191748053	-0.003203125	-0.0281875	
10	0.223706052	-0.003203125	-0.0281875	
11	0.191748053	0.001679688	0.01478125	
12	0.191748053	-0.003203125	-0.0281875	
13	0.159790039	-0.003203125	-0.0281875	
14	0.191748053	0.001679688	0.01478125	
15	0.159790039	-0.003203125	-0.0281875	
16	0.127832025	-0.003203125	-0.0281875	
17	0.127832025	-0.003203125	-0.0281875	
18	0.127832025	-0.003203125	-0.0281875	
19	0.127832025	0.0065625	0.057749998	
20	0.127832025	0.001679688	0.01478125	
21	0.095874026	-0.008085937	-0.071156248	
22	0.127832025	-0.003203125	-0.0281875	
23	0.127832025	-0.003203125	-0.0281875	
24	0.127832025	0.001679688	0.01478125	
25	0.159790039	-0.003203125	-0.0281875	
26	0.191748053	0.001679688	0.01478125	
27	0.191748053	0.001679688	0.01478125	
28	0.223706052	0.001679688	0.01478125	
29	0.191748053	0.001679688	0.01478125	
30	0.191748053	-0.003203125	-0.0281875	

Figure 9: Output to Spreadsheet

Sample Outputs

Figures 10, 11, and 12 show two sample outputs from the completed device generated using Visual Basic and Microsoft Excel. Here the user has plotted the data he received as a spreadsheet from one trial. Figure X was generated with a blade that did not break in the device. As the bend increased, the torque felt by the sensor also increased to approximately 1 in-lb at 75 degrees. The piece of steel did not break; the increase in torque remained linear throughout the test until reaching seventy five degrees. There appears to be no evidence of strain hardening or failure, as the slope does not change.

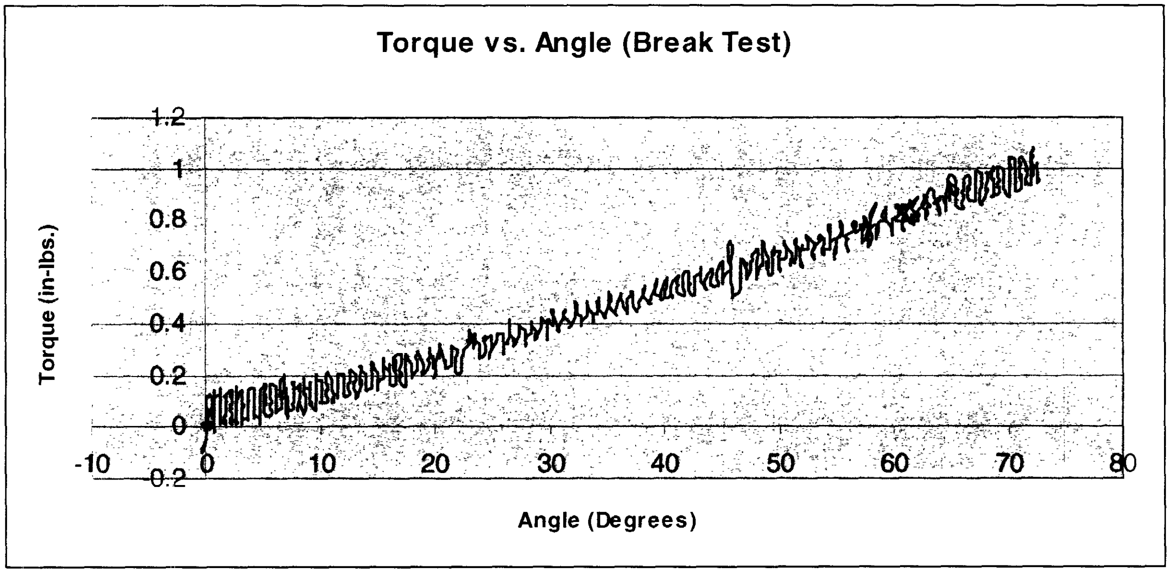


Figure 10: Torque vs. Angle Sample Output #1

Figure 11 is different from Figure 10 in that the piece of steel tested in the latter fractured. It is clear to see that at approximately 28 degrees and .7 in-lbs, the steel fractured and no longer resisted the bending of the motor. In both Figures, it is easy to see the small "chatter", or up and down motion, in the data.

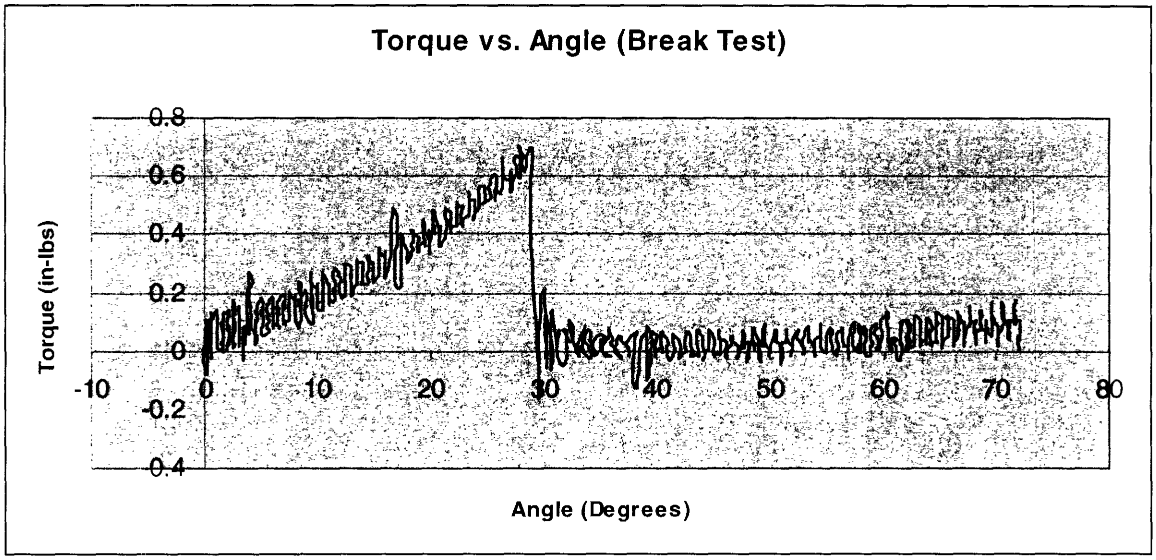


Figure 11: Torque vs. Angle Sample Output # 2

Finally, in Figure 12 the steel tested seems to have broken at 65 degrees and 2.25 in-lbs. Also, the slope of the plot seems to vary; it is possible this steel underwent some hardening and then failure at around 35 or 40 degrees.

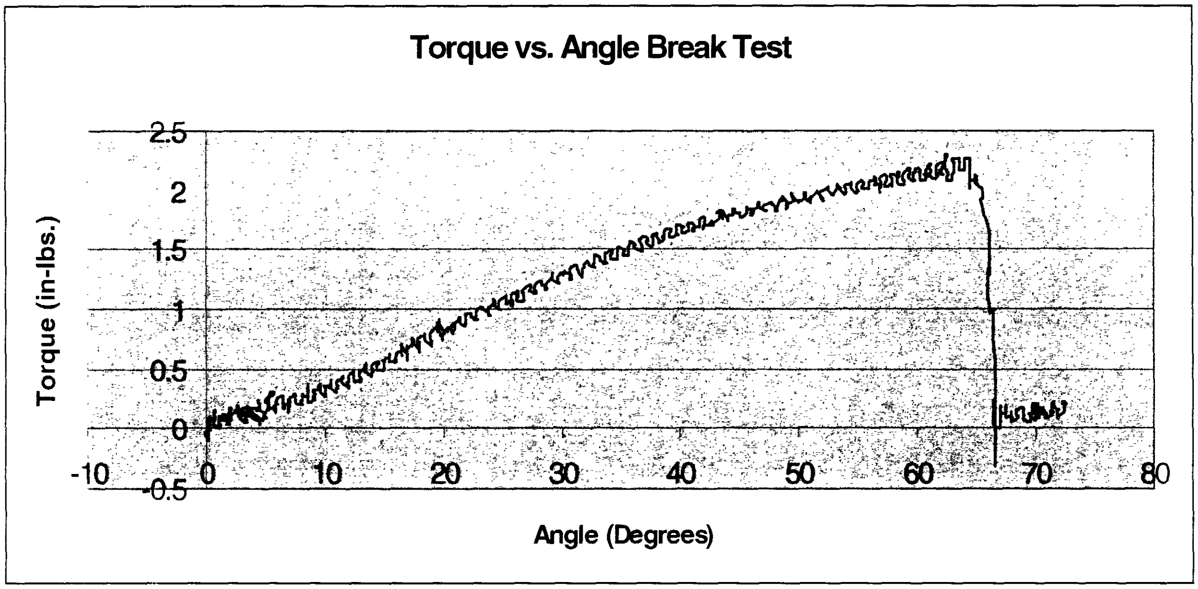


Figure 12: Torque vs. Angle Sample Output # 3

Discussion

The three graphs shown in Results clearly show that the device was able to discern between a piece of steel that fractured and a piece of steel that did not. In Figures 11 and 12 the steel fractured at approximately 28 and 65 degrees, the reading of which was the ultimate goal of the device. As the other graphs show, the device was able to discern between three very different behavior patterns; non-fracture, ductile fracture, and brittle fracture. Figure 13 shows the two slopes seen in one of the tests. These two slopes perhaps could account for strain hardening followed by ductile failure. Again, the measuring device was successful in its ability to tell the difference between the way these three pieces of steel, or blades, bent. The specifications of the blades tested are unnecessary for the purposes of showcasing the devices capabilities.

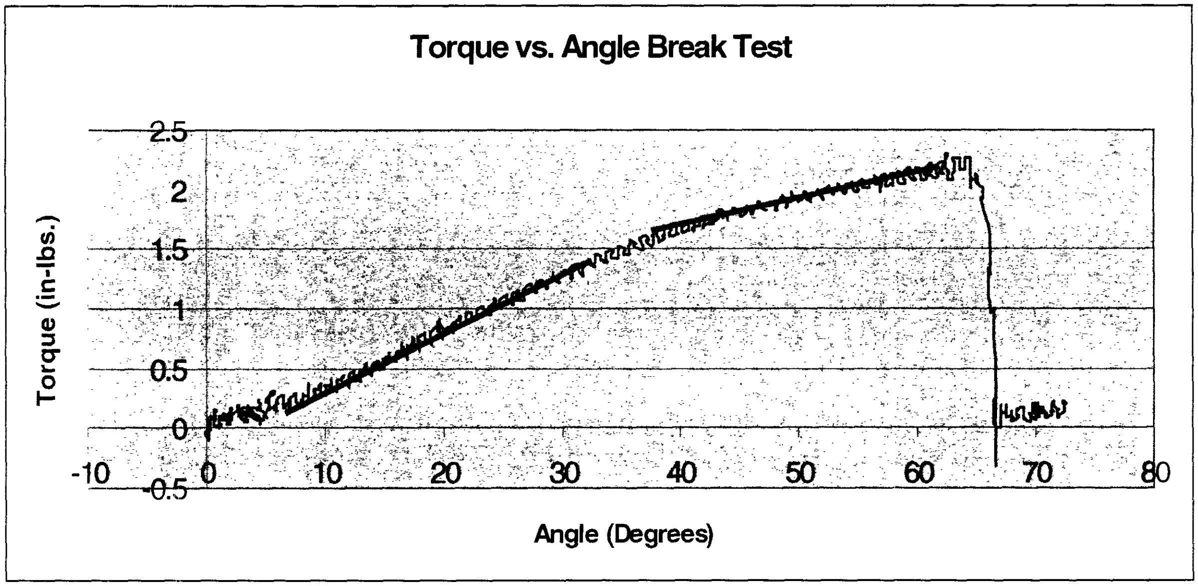


Figure 13: Strain Hardening followed by Failure in Thin Steel

Mechanically, the final device was robust and performed well. The flipper arm moved accurately to the intended position of the user at the intended velocities and accelerations. The air cylinder and pressure sensor were not implemented yet in this tool.

The weight of the break device forced the aluminum plate to bow in the center but reinforcing aluminum strips were screwed underneath the plate. Aligning the devices in series, perfectly linear was very difficult and depended largely on the craftsmanship of the mounts for the sensor and motor. As it was, the sensors had to be zeroed to alleviate about .25 in-lbs of torque that were being exerted at rest due to misalignments. It was assumed that the turning of the flipper arm by the motor would not increase or decrease this offset, that the .25 in-lbs was a constant offset. This offset was very difficult to eliminate, it was believed, partly due to the high sensitivity of the sensor. Further, aligning the devices was very difficult, an easy system for doing so was not considered when designing the device.

The computer interface was functional and intuitive but had bugs, resulting in a restart being necessary every so often. For example, accidentally pressing a button multiple times might lead to an error. Essentially, more error-handling scripts would have helped the robustness of the code. Inexperience with software engineering was to blame here but this did not effect the basic functioning of the program. An engineer without too many extraneous button presses could successfully use the program for an endless number of tests.

There were a few software modifications that could have improved the overall functionality but were cut out due to fixed deadlines. It was hoped that saving multiple runs as one binary would be possible but as was, each test had to be saved in its own binary file and recalled individually. Saving, recalling, and plotting a batch of individual tests by opening one binary file was the goal, but this level of complexity was not reached, again due to time constraints.

The graph output in the Visual Basic interface was incorrect in that the positional data was presented as a negatively sloped line. As the angle of the flipper increased a positively sloped line was expected, but unfortunately the torque sensor was positioned such that the movement of the flipper arm produced negative voltage rather than positive voltage. Instead of seeing a positively increasing line as the flipper arm moved, a negative line was seen. This was not a serious error, the sign of the output was simply flipped through the software, but it was something worth fixing in a future generation.

Conclusion

Error

The noise or chatter in the results, seen as small sinusoidal fluctuations, was unexpected and unfortunate, but one explanation was that the resolution of the torque transducer and the lack of a good calibration method for aligning the devices on the aluminum mounting plate. A quick and effective method for making sure the devices were lined up perfectly in series was not considered into well into the design process. By modifying the aluminum plate and the mounts, one could use set screws to align the devices then set them in place. As the system is now, aligning the devices and locking them in place is a time-consuming process that is difficult to do properly.

In addition, the mounts were machined using a hand operated mill with a digital readout so there could have been discrepancies in the desired specifications and resulting specifications. Tiny unnoticeable discrepancies could definitely be notice by the torque sensor, adding to the initial offset. Finally, the aluminum plate and mounts were spray painted, possibly yielding an uneven, grainy surface with which to align devices. As the mounts were tighten and loosened through use and alignment, the paint became chipped. Perhaps, spray painting the surfaces was not necessary, although it did aid in seeing pieces of metal against the surface of the aluminum plate.

Finally, the choice of sensor raised some concerns; a 1 Nm or 8.8 in-lbs sensor may not have been the right tool for our purposes. Some of the noise from the sensor may be due to the sensor not being as accurate in the low end of its measurement range. A 10-Volt sensor that only receives between .1 and 1 Volt may have some low-end resolution issues. If we had used a .2 Nm sensor for example, perhaps our readings would have been more consistent, resulting in less noise or chatter in the plots.

All of these factors created a situation where absolute measurements were difficult to calibrate and put too much faith in. The device was still useful for its original intent, relative measurements, or comparisons between two different pieces of steel. It was precise but not necessarily accurate. Modifications to the device, such as an attachment with which to hang weights from, could yield measurements that were definitely accurate.

Use

This device will be used to test the properties of any modifications that engineers may make to steel products. If a manufacturing process is modified so that a piece of steel's rate of cooling is changed then that will certainly affect the materials properties. The effects of such a change could be monitored with this device. Engineers may test their current manufacturing process versus a new one on the basis of bending moment using the device. Also, the device can be part of any general integrity test on a product, new or old. When designing a machine, engineers have to consider fatigue issues. This testing device could be used to test the life of machine components against fatigue and failure by repeated bend testing.

Creation of Device

An important conclusion that was realized through this project was that especially within the confines of a large corporation, creating one's own measuring device versus a vendor-purchased one is sometimes advantageous. Designing an accurate, robust device was difficult but purchasing a similar product, so suited to Gillette's needs is difficult to imagine. Perhaps Gillette could have supplied specifications to an outside engineering company to design such a device but the advantages to doing it in house are apparent. There was no overhead in creating the device; parts and the labor of one engineer were the main expenses, there was no consideration of profit. Further, as it was being created, the device was redesigned and modified, yielding a superior product in the end. In addition, progress on the device could be held in check, closely monitored by a manager. Accountability for an engineer designing a device in-house is important while it is impossible to hold vendors to their delivery dates. Finally, creating a device in-house avoided questions of secrecy and proprietary information, a serious consideration for a company so dependent on key technologies making their product superior to their competitors.

Recommendations

The next generation of this device should use a different torque sensor, one with a tighter measurement band, not much greater than 2 in-lbs. In addition, a quick and effective method for alignment of the devices should be considered. If this is difficult, at least a method for testing the correctness of the alignment should be created. Finally, an arm attachment to hang weights from that could attach to the measuring shaft of the torque sensor should be designed. This arm with a weight hanging from it, coupled with readings from the torque sensor, could tell the user how absolutely accurate his readings were. Essentially, they could use the physical weights to zero the device.

Acknowledgements

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Thank you to Professor Blanco for giving me valuable advice concerning this project and supporting me through four years at MIT.

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"Engineering Stress-strain Curve" 1999 INI International. May 1, 2005. www.Key-to-Steel.com (**Figure 3 Borrowed from Website**)