University of Manitoba
Department of Mechanical Engineering
MECH 4860 – Engineering Design

Final Design Report

Design for Plastic Film Measuring Device to Improve Accuracy and Repeatability of Print Repeat Measurement

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Winpak Ltd.

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Executive Summary

The objective of this report was to develop a design that would improve Winpak's current process of measuring the distance between repeated graphics printed on plastic packaging film. This to verify that the film graphic spacing is within the tolerance zone as specified by Winpak's clients. The most important requirements for the design were as follows:

- Must be accurate to ± 0.5 mm
- Measure up to 1650 mm in length
- Must be a repeatable measurement
- No sacrifice to operation time

The final design was sub-divided into four main sections; film flattening, measurement method, device raising mechanism, and eye mark alignment. The team sourced a vacuum table with a surface area of 1800 mm by 900 mm to flatten the film prior to the measurement. The vacuum table has an air flow adjustment valve to vary the suction force to account for different plastic film thicknesses. The surface of the vacuum table is anodized to prevent oxidation, and is finished with an anti-static agent to eliminate accidental static charge to the operator. A Mitutoyo® linear scale was sourced as the measurement device. This scale is fixed in the center of the table, and has an overall effective measurement range of 1700 mm, which exceeds the requirement of 1650 mm. The linear scale has a detector head that can travel along the total length. As the detector head moves, its position is displayed on the compatible digital readout (DRO) counter. This counter can zero the measurement of the detector head at any location. Additionally, the counter can output the data to a computer if so desired, but this was out of the project scope. This linear scale is accurate up to ±7 μm, which is well within the requirements of ±0.5 mm. A raising mechanism was designed to lift the linear scale off the table surface to allow for placement of the film. The raising mechanism has triangular brackets that extend from the back edge of the table to the linear scale. The back of the bracket is attached to friction hinges which will keep the scale from dropping onto the table surface, causing damage. Finally, the team designed an eye mark locator which aids in the alignment of the plastic film. This piece is attached to the detector head of the linear scale, and has a perpendicular straight edge that can be quickly used to align the eye marks. The team also specified a straight calibration line on the table which will be used to align the row of eye marks to the linear path of the detector head. The final cost of parts and material, not including labour is approximately $5700 CAD.

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1.0 Introduction

Winpak produces plastic film packaging which is used in various markets around the world including food, dairy and medical supply packaging. These plastic films have printed graphics that give the consumer information about the contents of the packaging, as seen in Figure 1.

Figure 1: Packaging showing content information.

Once the rolls of film are produced by Winpak, they get sent out to Winpak's customers. These companies use packaging machines to fill the film packaging with their products. The graphics printed on the film produced by Winpak must be highly accurate. If the spacing between these graphics is not precise enough for Winpak's clients, their packaging machines will fail. This will cause Winpak's manufactured plastic film packaging to be returned, causing economic loss. An example of the rolls of film produced by Winpak can be seen in Figure 2.

Figure 2: Roll of plastic film produced by Winpak.

The current process used by Winpak to measure the graphics printed on the plastic film is to tension the plastic film sample by hand while using a tape measure to measure the distance between eye marks. Eye marks are small rectangles printed on the film used to measure the spacing between graphics and can be seen below in Figure 3.

Figure 3: Pre-existing film graphic measurement process

Winpak's customers specify the number of repeats to be measured (that is the number of eye marks to measure) and the allowable range of this measurement. This means that each completed measurement can span multiple repeats up to 1650 mm. Each row of printed graphics is measured to ensure the spacing is consistent across the width of the film. Two of these rows of graphics can be seen here in Figure 4.

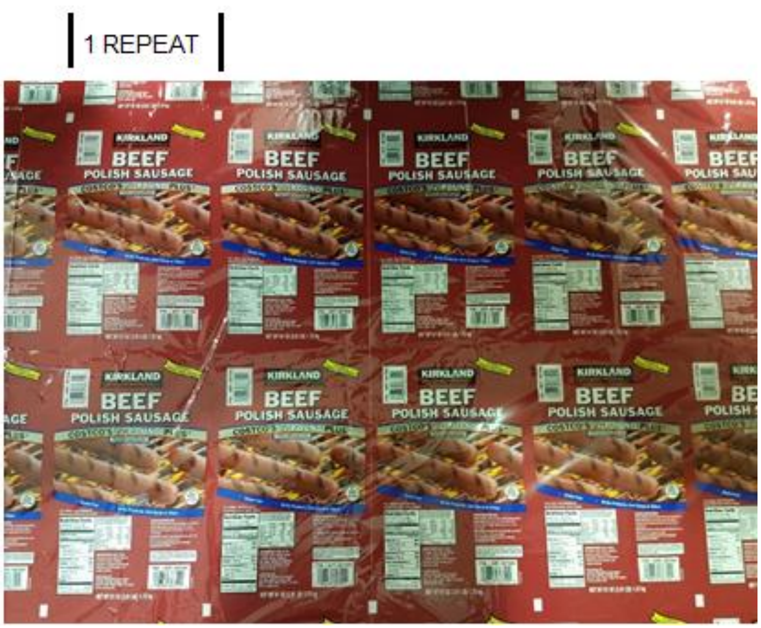

Figure 4: Multiple rows of graphics to be measured.

1.1 Project Objectives

The objective of this project is to create a design that will increase the accuracy and repeatability of this plastic film graphic measurement without sacrificing operation time or requiring an additional worker for larger measurements. The team will also work with Standard Machine, to ensure they have all the information required to create a working prototype for Winpak.

1.2 Project Deliverables

The deliverables of this project are as follows. A complete bill of materials will be provided to the client, allowing the purchase and assembly of sourced components. Layout drawings will also be included to allow for the fabrication of any custom or non-externally sourced parts required to fabricate the design.

1.3 Project Requirements

Winpak has helped the design team to identify the requirements that this project will meet to allow for the successful completion of this project. The design will meet the following requirements, listed below.

- Safe operation of device
- Meet the required accuracy of $\pm$ 0.5 mm
- Measure the maximum range of repeats, up to 1650 mm in length
- Allow a suctioned film width of 800 mm
- Enable measurement time equal to or less than the pre-existing process
- Account for various film properties
- Allow for careful tension in film without introducing inaccuracies in measurement
- Accurately identify the distance to be measured
- Utilize available power source

1.4 Final Design Expectations

A summation of the expectations of the design can be found below. These expectations will serve to increase client satisfaction in the final design.

- Easy to maintain
- Long lasting
- Easy operation and simple on-site training

- Accurate film placement and eye mark alignment
- Low power consumption
- Minimal noise level
- Highly repeatable measurement with the required accuracy
- A project space large enough for all film samples to be measured
- Digital measurement readout

2.0 Sub-Component Detailed Design

The final design was addressed in sections, with different components sourced to address the various needs and requirements of the project. The first main component is the vacuum table, which addresses the need to have the plastic film properly flatted for measurement. Next is the linear scale system, which is the component that is used to take the measurement and display its value. Following that is the linear scale positioning system, which allows the linear scale to be moved to increase space for placement of plastic film. The last component is the eye mark alignment system, which is used to precisely locate the plastic film on the table surface. The concept selection for each sub-component leading up to the final design can be seen in Appendix A. A detailed prototype and proof of concept analysis was performed to establish the feasibility of the design, and can be seen in Appendix B.

2.1 Vacuum Table

To take an accurate measurement, the film must be completely flat and not stretched or deformed in any way that will negatively affect the film measurement. The flattening of the film to the measurement surface without stretching can be achieved by using an equally distributed downward force on the entire film area. The downward force on the film can be provided using suction from a vacuum table. The vacuum table produces a suction force that allows the operator to flatten the plastic film on the surface without any curling or wrinkling of the film. The table surface is 1800 mm by 900 mm with a vacuum area of 1700 mm by 800 mm. These dimensions were specified according to Winpak's requirement.

The vacuum table provides multiple features in addition to holding down the film for the measurement process. In the following section, these features are introduced and explained.

2.1.1 Vacuum Table Surface

The table surface is made from anodized aluminum. This anodization improves the corrosion and abrasion resistance of the aluminum tabletop [1]. Due to realistic operating conditions, impurities will be introduced to the table surface, requiring the need of increased corrosion resistance. As well, the anodized surface will make scratches or damage more visible indicating when maintenance is required.

The table surface is also coated with an anti-static agent to prevent static shock to the operator, and to reduce static cling between the film and the table. In addition, the anti-static coating will help prevent the plastic film from wrinkling while being laid down on the table surface.

The holes on the table surface allow the film to be pulled down to the surface of the table with a specific amount of force coming from the vacuum pump. The holes are relatively small (1.37 mm diameter) in order to prevent the film from forming a dimple on the surface.

2.1.2 Drilled Aluminum Honeycomb

The aluminum honeycomb panel is sandwiched between the top and bottom aluminum surfaces. The honeycomb geometry inside the aluminum panel provides high compressive strength with a low density. The honeycomb voids inside the vacuum table allow the air to flow freely, helping to apply the vacuum force evenly across the top surface to secure the film in place. The aluminum honeycomb panel is surrounded by an aluminum solid bar frame to provide more deflection support and to provide a drilling location for hinge mounting considerations. The honeycomb can be seen in Figure 5.

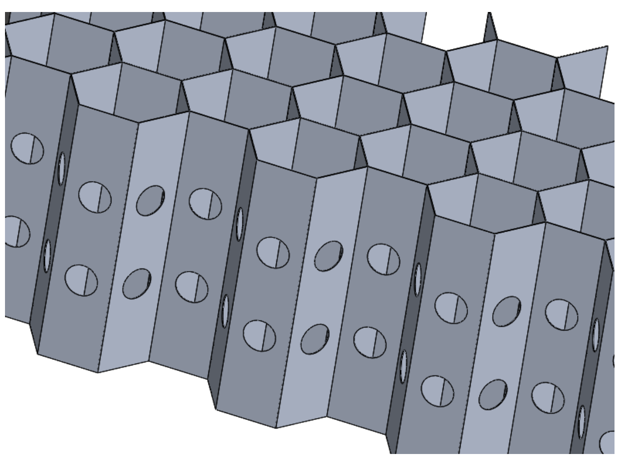

Figure 5: Drilled aluminum honeycomb for vacuum table.

2.1.3 Air Adjustment Valve

The designed product will be exposed to variety of plastic films with different textures and thicknesses. Difference in quality and thickness of films requires different vacuum power to hold the film in place. The air adjustment valve is a method for adjusting vacuum power to the table.

Air flow can be controlled by turning the knob until it reaches its desired vacuum power. The valve will be placed underneath the table where the operator has easy access. The valve can be seen in Figure 6.

Figure 6: Vacuum table air adjustment valve example [2].

2.1.4 Pump

Providing the suction force is the vacuum pump, and the team's required pump functionality is to provide even force to completely flatten the film. The plastic film requires minimum vacuum force to hold down to the surface and therefore, this application requires a low power vacuum motor to provide the sufficient suction force.

The team chose the smallest vacuum motor available from the vacuum table manufacturer for compatibility between components. The vacuum motor specified for this application has a vacuum power of 6.2 kPa [3], which is adequate to secure the plastic film. TABLE I shows the specifications of the vacuum pump.

TABLE I: GPI-VM32-150 SPECIFICATIONS

Model Number	GPI – VM32 – 150
Inlet/Outlet Ports Diameter	1.5"
Voltage	110 V
Amps (max rated)	3.0 A
Max Vacuum	25 in·H_2O
Max Airflow	35 SCFM
Maximum Temperature Rise	35°C
Weight	10 kg

2.2 Linear Scale System

This section outlines the features and functionality of the main components of this design, the linear scale and it's associated digital readout (DRO) counter. These two devices work together to produce a highly accurate linear measurement reading between two eye marks.

2.2.1 Mitutoyo® ABS AT715-1700

A Mitutoyo® ABS AT715-1700 linear scale was sourced to address the requirement of producing a repeatable measurement accurate to ± 0.5 mm. This scale can be seen in Figure 7.

Figure 7: Mitutoyo® ABS AT715-1700 linear scale [4].

The device is equipped with a detector head that can travel along the length of the scale. A measurement reading is generated as the detector head moves linearly, with the ability to zero the scale at any point, similar to how a digital caliper operates. With the linear scale mounted horizontally above the vacuum table, a distance can be measured between the eye marks on the plastic film by zeroing the detector head on the first eye mark, then sliding it down to the second eye mark, while taking note of the overall digital readout. The digital readout is displayed on the DRO counter, which is connected to the linear scale through a cable attached to the detector head. The DRO counter will be discussed more in depth in the following section.

The following table lists the features of the ABS AT715-1700 linear scale.

TABLE II: FEATURES OF ABS AT715-1700 LINEAR SCALE [5]

Detecting system	Electromagnetic induction system
Resolution	.000005”, .00005”, .0001” (0.0001mm, 0.0005mm, 0.001mm, 0.005mm) (selectable by DRO counter setting)
Effective measuring range	1700 mm
Accuracy 68°F (20°C)	± 7 µm
Response speed	50 m/min
Dust/water protection	IP67
Sliding force	< 1.124 lbf

As shown in TABLE II, the accuracy of the linear scale is ± 7 µm which is well within the required accuracy of ± 0.5 mm. In addition, the device has the highest rating (IP67) for resistance against solid objects (tools, wires, dust, etc.) and liquids (immersible in water up to 1 m), so there is no concern for accidental spills or handling of the device. The detecting system for the measurement uses an electromagnetic induction system, which is explained in depth in Appendix A.

2.2.2 Mitutoyo KA-200 DRO Counter

The second component of the linear scale system is the DRO counter, which is responsible for taking the output produced by the ABS AT715-1700 and displaying the digital readout of the measurement. The specific DRO counter sourced for this application is the Mitutoyo KA-200; a list of its features is shown in TABLE III.

TABLE III: FEATURES OF KA-200 DRO COUNTER [5]

Order No.	**174-173A**
Scale input ports	2*
Display	7-digit LED and a negative [-] sign
Functions	Zero-setting, preset, counting direction setting, mm/inch conversion, ABS/INC coordinate selection, computer output
Power supply	120V AC, 50/60Hz
Operating temperature	32°F to 104°F (0°C to 40°C)

Mass	2.43 lbs (1.1kg)

*: Available as a 1-axis counter by changing the parameter setting

Notable features of the KA-200 counter are the ability to zero the measurement at any location, and output coordinate data to a personal computer through a RS-232C connector. Should the client wish to use the computer output function, a conversion cable needs to be purchased to convert between USB and RS-232C. This cable is included in the BOM measuring system category in section 4.2.

2.3 Linear Scale Positioning Mechanism

To effectively utilize the vacuum table suction space, the measurement sensor must be raised out of the way to allow for the film placement. The raising of the measurement sensor is achieved by a position (friction) hinge in this design. The position hinge sourced by the project team will allow the operator to raise the measurement sensor up and out of the way to allow an open table surface for film placement, as seen in Figure 8.

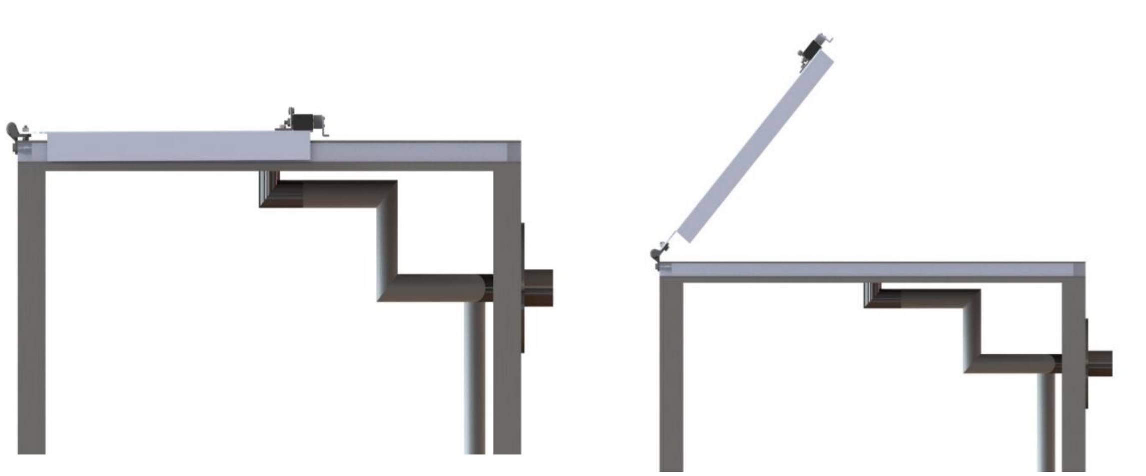

Figure 8: Linear sensor raising mechanism down and up.

This linear scale positioning process is important to ensure the operator has clear and safe access to the entire suction surface so they can line up the eye marks to produce an accurate measurement.

2.3.1 Position Hinges

Position hinges were sourced to hold up the sensor, preventing the operator from requiring one hand to hold up the sensor while trying to position the film with the other. This allows for safe and convenient operation of the design. The position hinges can be observed below in Figure 9

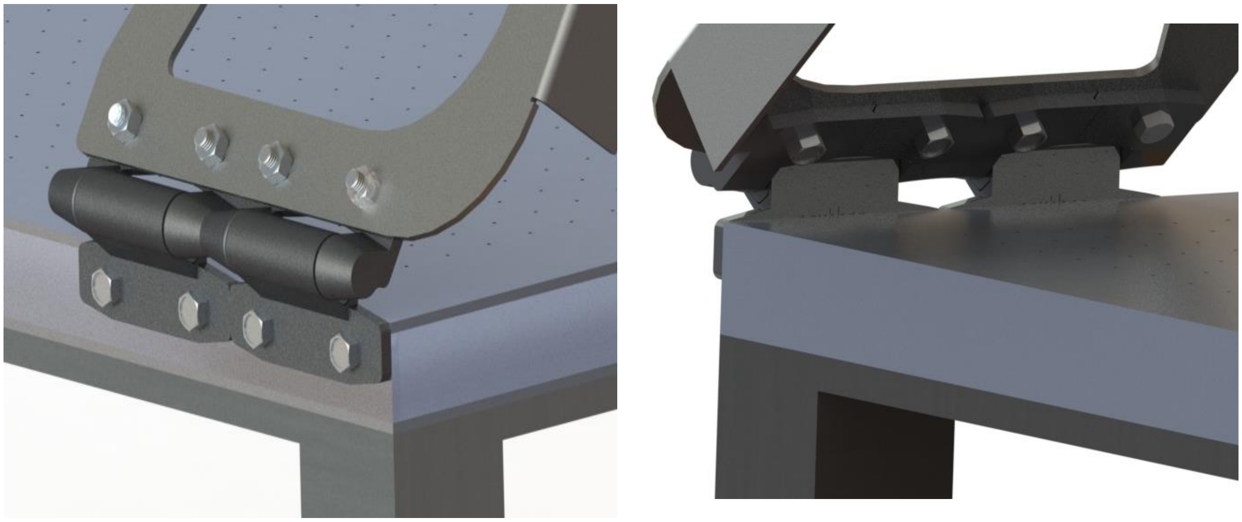

Figure 9: Position hinges front and back.

To determine the strength requirements for the hinge, a calculation was completed. Sample calculations used to source the hinges can be found in Appendix B. The hinge calculations determined a minimum torque of 6.05 Nm per hinge was required to support the measurement arm. Each hinge that was sourced has a specified torque of 9 Nm which will serve to increase the longevity and reliability of the design.

Due to the forces acting on the hinges, the hinges must be securely mounted to the table. For the hinges to be mounted, the team specified a vacuum table frame manufactured from one inch square aluminum bars, located internally along the perimeter of the table. This can be seen below in Figure 10.

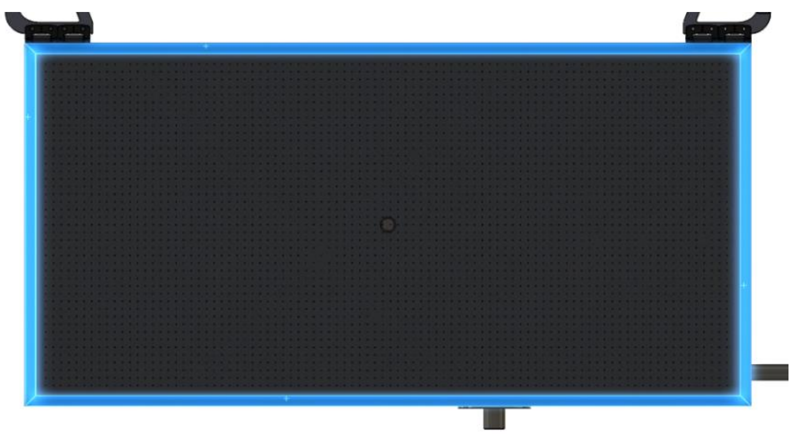

Figure 10: Aluminum bar frame located inside table edge.

The solid aluminum channel will allow for screw threads to be tapped into the table to mount the brackets. Below, one can see the hinges mounted to the aluminum bars inside the table in Figure 11.

Figure 11: Hinges mounted to aluminum bar inside table.

2.3.2 Mounting Brackets

Connecting each set of two hinges to the linear sensor is a mounting bracket, seen in Figure 12.

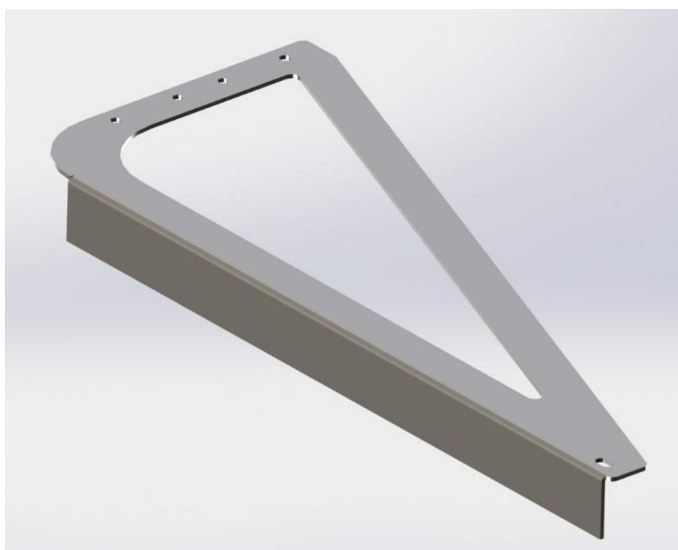

Figure 12: Hinge mounting bracket.

These mounting brackets are designed to support the weight of the linear sensor to allow the operator to move the sensor up and away from the measurement space. The mounting brackets used with the hinge have an additional lip bent 90^0 downward, to provide stability in the vertical direction when supporting the weight of the measurement sensor. This will enable the operator to place the sensor at any angle for jobs with specific requirements.

2.3.3 Support Blocks

Attached to each mounting bracket is a support block, seen in Figure 13.

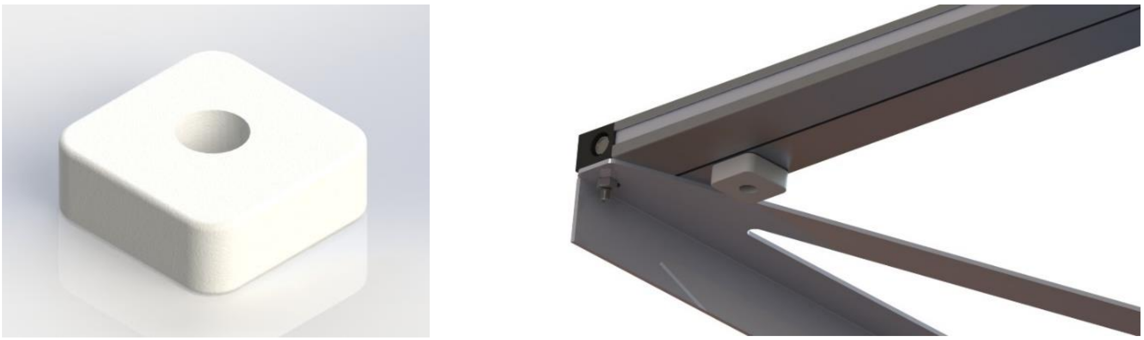

Figure 13: Support block used to rest measurement arm on table surface.

The support blocks are used to stop the measurement sensor at the same height for each measurement. These blocks have rounded corners and edges to prevent damage to the film. These support blocks will be located near the edges of the table to support the weight of the sensor without intruding on the measurement space.

2.4 Eye Mark Alignment System

This section describes the design of the device that will be used to locate the eye marks once the plastic film is flat and properly tensioned.

The focus for the design of the eye mark locator was to increase the accuracy at which the detector head on the linear scale can be aligned with the eye marks on the plastic film. The repeatability of alignment is crucial in the overall accuracy of the measurement.

For precise alignment, the eye mark locator is attached to the outer face of the detector head and has a protruding edge that is to be lined up with the eye marks, as seen in Figure 14 and Figure 15.

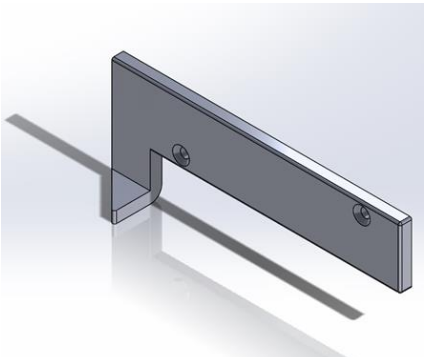

Figure 14: Eye mark locator.

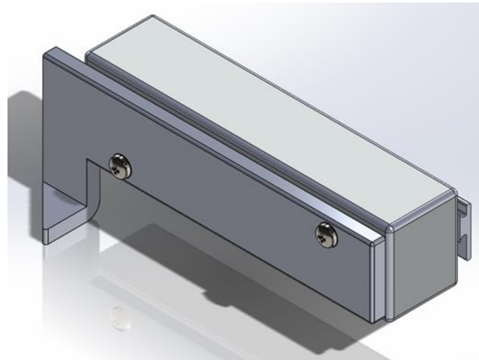

Figure 15: Eye mark locator mounted on detector head.

Due to the position of the linear sensor, there is a gap between the detector head and the surface of the vacuum table, shown in Figure 16. In this situation, the gap adds measurement error when trying to align the eye mark if the operator is not directly above the device.

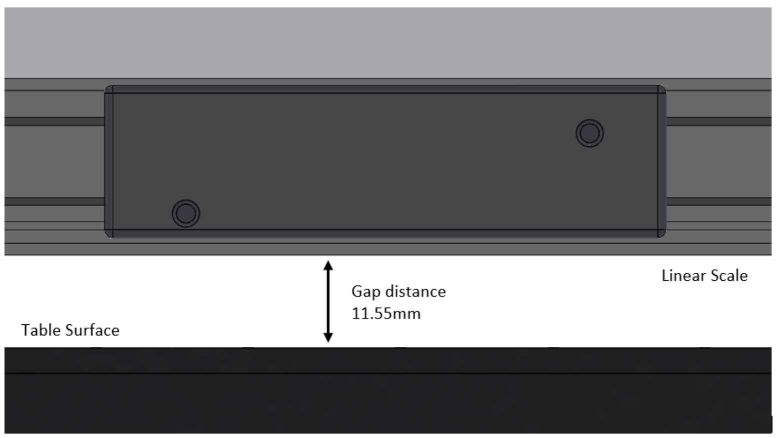

Figure 16: Gap between linear scale and table.

The exact dimension of the extended piece of the eye mark locator was designed to reduce this gap. This feature of the design shortens the gap distance to 2.75 mm, which will make the alignment more repeatable.

Figure 17: Linear scale detector head with addition of eye mark locator.

As shown in Figure 17, a simple metal L-shaped extension piece was designed to shorten the gap between the locating reference point and the table. Utilizing the two screw holes on the detector head, the team incorporated two holes in the corresponding position on the L-shaped alignment piece for mounting purposes. A detailed drawing can be found in Appendix D. This design is cost efficient, can easily be integrated onto the measurement device, and would have minimal maintenance requirements.

The working principle of this concept is the straight edge which allows accurate placement with the edge of the eye mark, shown in Figure 18.

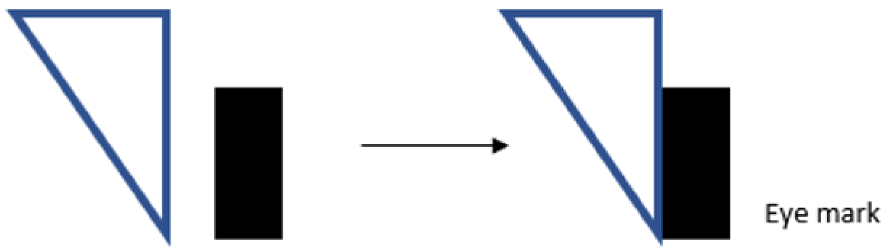

Figure 18: Triangular block concept for locating eye marks.

When the linear scale is raised above the table surface for film placement, correct initial positioning of the plastic film can be difficult. To aid in this process, the team specifies that a straight calibration line is etched into the table surface that marks where the linear scale would align when in its lowered position. The eye marks would be aligned to this calibration line when setting up the plastic film.

Figure 19: Calibration line on vacuum table for eye mark alignment.

As seen in Figure 19, a straight line etched across the length of the table will allow for precise eye mark placement while the linear scale is up and out of the way.

3.0 Final Detailed Design

This section shows the entire system of the final design, as well as instructions for the operation of the device.

3.1 Design Overview

This design consists of four main components. First, a vacuum table which is used to flatten, tension and position the film for measurement. Second, the linear sensor which is used to make the actual measurement. Third, the raising mechanism which is used to raise and lower the measurement arm. Last, the eye mark alignment system, which is used to identify the correct position of the film.

The raising mechanism allows the operator to lift the measuring equipment out of the way for safe and convenient film placement. The suction of the vacuum table helps smooth out wrinkles and holds the film in place once the top of the eye marks are aligned with the line running across the measurement surface. The eye mark locator is zeroed on the edge of one eye mark (or graphic border if no eye marks are present) and is moved to the same edge of the eye mark on the boundary of the repeats specified by Winpak's client. This will provide a digital output and reading to be used with Winpak's data capturing equipment. This reading can be compared to the allowable range for the measurement as specified by Winpak's client on a per job basis.

The final design can be seen in Figure 20.

Figure 20: Final design and all components.

3.2 Operation Instructions

Step 1: Activate the vacuum pump and make sure the vacuum table is powered on.

Action: Turn on the power by pressing the switch.

Step 2: Make room for plastic film to place on the vacuum table.

Action: Slowly lift the measurement sensor with both hands.

Figure 21: Positioning mechanism lowered and raised (step 2).

Step 3: Place and flatten plastic film on the table.

Action: Place the plastic film on the surface of vacuum table with both hands, smooth out wrinkles and bubbles.

Step 4: Align the eye marks to be measured with the straight calibration line for correct initial positioning of the plastic film

Action: Turn down the air adjustment valve, then carefully move the plastic film with both hands to align the eye marks with the calibration line.

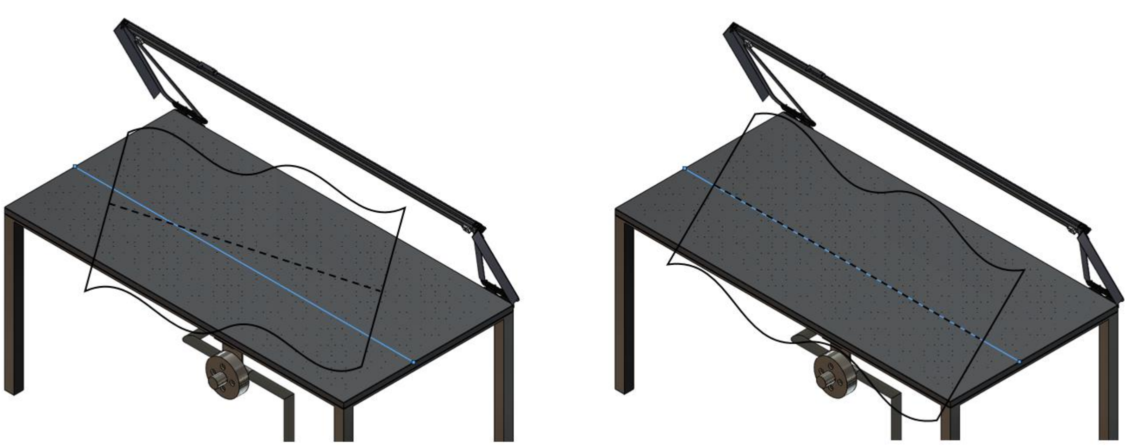

Figure 22: Film alignment with calibration line (step 4).

Step 5: Start the measurement process.

Action: Slowly lower the measurement senor with both hands until the supporting blocks touch the table.

Step 6: Determine the initial position of the measurement length.

Action: Move the sliding detector head over the first eye mark, and align the eye mark locator with the edge of the eye mark.

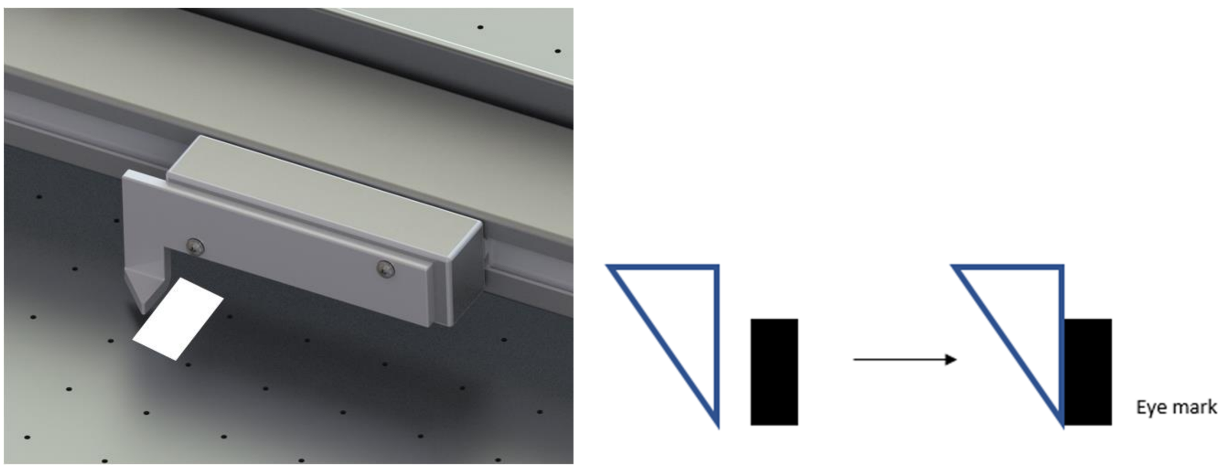

Figure 23: Eye mark alignment (step 6).

Step 7: Zero the scale.

Action: Press the corresponding axis zero button that has a circle around it.

Figure 24: DRO (step 7).

Step 8: Measure the distance between the two eye marks.

Action: Slide the detector head to the second eye mark.

Step 9: Determine the final position of the measurement length.

Action: Align the eye mark locator with the edge of the eye mark.

Step 10: Record data.

Action: Record the digital readout shown on the display screen.

4.0 Project Deliverables

The deliverables to the client include the detailed part drawings, the bill of materials (BOM), and the correspondence with Standard Machine to prepare for prototype fabrication.

4.1 Part Drawings

As per the client's request, detailed drawings have been provided and can be found in Appendix D. Drawings for the parts to be manufactured are included, as well as reference drawings for the sourced products.

4.2 BOM and Cost

TABLE IV shows the BOM and the cost of each material or part specified. Quotes for purchased parts can be seen in Appendix C.

TABLE IV: COMPLETE BOM AND PRICE BREAKDOWN

Distirbutor	Part #	Part Name	Description	Qty	Units	Unit Cost	Cost
VacuumTables.com	VBAH-1141-GPI	Vacuum table	1-1/4" Vacuum table w/ aluminum honeycomb	1	ea	$2,145.00	$ 2,145.00
	GPI-VM32150	Vacuum motor	1/3HP, 110-115/220-230V, 1PH 50/60 HZ, 3.0-3.6/1.5-1.8 Amps, 1.5 Port O.D.	1	ea	$ 901.00	$ 901.00
	AFV150-BVGPI	Air flow valve	On/Off air flow ball valve with 1.5" (3.81cm) In/Out O.D. port	1	ea	$ 184.00	$ 184.00
	GPIH115HDE	Vacuum hose	1-1/2" I.D. heavy duty grey flexible hose	25	ft	$ 6.98	$ 174.50
	GPIHC114134	Vacuum hose clamp	1-1/4" - 1-3/4" (32-44mm) in diameter	4	ea	$ 11.87	$ 47.48

	GPIAFV-15	Adjustment bleeder valve	Adjust air flow to holes in vacuum table (1.5" diameter port)	1	ea	$ 374.43	$ 374.43
Thomas Skinner	MTI-174183A	KA-200 Counter	Digital readout for linear scale	1	ea	$ 581.09	$ 581.09
	MTI-539824	ABS AT715-1700	Linear scale	1	ea	$ 794.83	$ 794.83
	600-22-MIG4A-KB-USB	Conversion Output cable	USB for Mitutoyo MIG-4A Digimatic/RS-232 Interface Unit (optional)	1	ea	$ 219.00	$ 219.00
Southco	E6-10-680S-50	E6/ST- Constant Torque	Torque hinge to mount linear scale to table (price reflects order of 10)	4	ea	$ 42.65	$ 170.60
Metal Supermarket	AA6061/11418	Aluminum Angle 6061T6	Angle stock for stiffening linear scale (78.74inches)	1	ea	$ 33.66	$ 33.66
McMaster Carr	91287A136	18-8 Stainless Steel Hex Head Screw, M6 x 1mm Thread, 16mm Long	Bolts to mount hinge to bracket (50 pack)	23	ea	$ 10.24	$ 10.24
	92000A215	18-8 Stainless Steel Phillips Rounded Head Screw, M4 x 0.7 mm Thread, 5 mm Long	Screws to mount eye mark locator (100 pack)	2	ea	$ 8.26	$ 8.26
	91828A251	18-8 Stainless Steel Hex Nut, M6 x 1mm Thread	Nuts for bolts (100 pack)	23	ea	$ 11.08	$ 11.08
		Total		**89**			**$ 5,655.17**

4.3 Standard Machine Correspondence

To ensure the parts could all be manufactured, and within spec, the team had been in contact with Standard Machine to discuss the designed components. Through a meeting with Standard Machine to review part drawings, the team was able to verify that every component was able to be produced at that machine shop with no further considerations needing to be made.

5.0 Future Considerations

There are multiple potential future considerations Winpak may want to explore before procurement of the later tables. These considerations are explained below.

5.1 Raising Mechanism

The first future consideration is the raising mechanism. These hinges were sourced for simplicity of manufacturing and maintenance, ease of use and safe operation. Other mechanisms could be considered to replace the hinge as the sensor raising mechanism in the design. This could allow for lock-in-place raising of the measurement sensor or automated raising with a motor. When considering an improvement for the raising mechanism one must consider the following, a potential pinching hazard, device longevity and simplicity of mounting.

5.2 Hinge Mounting Brackets

Next, the brackets used to support the measurement sensor have received added support in the form of attached L brackets used to prevent deflection in the vertical direction when supporting the full weight of the sensor. These brackets could be optimized to save weight (or shift weight toward the hinges), thus increasing the life of the hinges by requiring less torque to hold up the sensor and sensor mounts. This mounting bracket optimization could be a future consideration.

5.3 Eye Mark Alignment System

After an operator has experience using the current design, they may decide to change the eye mark alignment system. Future considerations could include adding a light source, magnifying glass, laser or other components to ease the line-up of the eye marks. This could depend on the preference of the operator; however, the accuracy of the alignment should be prioritized high when sourcing improvements as the eye mark alignment system is essential in the successful completion of a measurement.

An additional consideration for the eye mark alignment system are to increase the size of the L shaped eye mark location piece, or to add a handle by which the operator would move the detector head.

5.4 Measurement Sensor

Depending on the effectiveness of the chosen measurement sensor, an alternative may be considered. When sourcing a measurement sensor, one should remember the accuracy requirements and the time allowance for which the sensor would be used. The current sensor was sourced for its superior accuracy, ease of use and its digital readout and output.

A secondary measurement technique may also be explored. An additional measurement sensor could be used to double check the reading of the current linear measurement sensor to tell when re-calibration is necessary, or for convenience of choice for the operator.

Additional optimizations regarding the measurement sensor include potential mounting options for the DRO. Depending on the workspace, one may wish to permanently re-locate the DRO for convenience and ease of use.

5.5 Measurement Space

Also, the required table specifications may change over time. A larger table or one with a different sized suction space may help the operator flatten or prepare films with specific properties or geometries that may be difficult on the current suction space. Increasing the table size could help for large measurements; however, this would require more floor space and could be more difficult to line up the eye marks when completing measurements.

An operator may also wish to adjust the height of the table to allow for easy eye mark alignment under all operating conditions, or depending on the height of the operator. This table raising mechanism could be incorporated into the vacuum table when being sourced by the manufacturer for ease of use.

5.6 Overall Design

Last, features of this design may be determined to be unnecessary by the client over time. Changes to the raising arm, or the way in which the current sensor is mounted, moved and used may be considered. Instead of raising the measurement arm vertically, a horizontal hinge would allow it to swing out and away from the measurement space. An automated raising mechanism could be included to lessen the burden placed on the operator. The sensor could be located away from the measurement space and would have an eye mark locator that will span this distance to ease the film placement process.

The team agreed having the measurement sensor close to the eye marks (table top) would allow a greater accuracy by preventing inaccuracies caused by the following. Deflection caused by the eye mark locator closing a larger gap and possibly deforming when making a measurement, or by making the eye mark alignment more difficult by being subject to the position of the operator. This may be deemed unnecessary and could be eventually be reconsidered.

An automated suction control system (or pre-set vacuum powers) could be considered to ensure easy change of vacuum pressure for varying film properties (as opposed to the pre-existing air flow adjustment valve).

6.0 Conclusion

This project met all the specified requirements that was indicated by the client. The final design consists of the following:

- Vacuum table for film flattening
- Linear scale for taking the measurement
- Positioning mechanism to move the linear scale when placing the film
- Eye mark alignment system for precise alignment of printed graphic

The goal of the design was to improve the accuracy and repeatability of the current film measuring process. The final design meets the required accuracy of ± 0.5 mm as the measurement device is accurate to ± 7 μm. Additionally, the vacuum table improves the repeatability of the process by providing a constant flattening pressure across the table surface that does not vary from operator to operator. The design also improves efficiencies in the process by providing a digital readout, and the possibility to hook up the device to a computer to directly output the measurement data and eliminate the need for the operator to manually record the data. The team has provided all necessary engineering drawings, a detailed BOM, and had a meeting with Standard Machine in order to ensure that they have everything required to fabricate this design.

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Appendix A – Concept Selection

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A1.0 Concept Generation

The following section details the design approach and methodology taken by the design team to generate the preliminary concepts. Concepts for how the plastic film will be properly tensioned, the measurement instrument, and the eye mark locator are discussed below.

A1.1 Design Approach

The design approach taken by the team began by modularizing the problem into three main aspects: film tensioning, measurement instrumentation, and eye mark location. These three aspects can be easily integrated with each other, regardless of the chosen design. Internal and external generation methods that were used to generate the concepts are illustrated below.

A1.1.1 Internal Methodology

The methodology used internally by the project team to create and develop concepts is as follows. From the first client meeting, the problem was identified. Then the project team broke the identified problem down into sub-tasks. The project team brainstormed ideas individually to create solutions to each individual sub-task. The team then met and shared ideas about how to complete each identified task, offering input to allow an identification of concepts.

A1.1.2 External Methodology

Once a comprehensive list of solutions to each of the identified sub-tasks was created, research was assigned to allow a thorough understanding of the potential solutions

Through the internal and external methodologies described above, three concepts were generated for each aspect of the design.

A1.2 Film Tensioning Concepts

To take an accurate measurement, the film must be flat and tensioned. The film must be tensioned but not stretched or deformed in any way that will negatively affect the film measurement. Static charge must also be prevented, to allow the measurement to be as accurate and safe as possible. Additionally, calibration of the film tensioner is essential for the accuracy of the measurements due to varying film properties that exist in three different stages of the film fabrication process. The varying properties include film strain and thickness which would alter the amount of tension on the film that is required: The following film tensioning systems were considered: a vacuum table, a rubber cylinder, and a weight system.

A1.2.1 Vacuum Table

An effective way to eliminate wrinkles in the plastic film would be by use of a vacuum table. The table would use the force of air suction to pull the plastic film down onto the surface of the table top where the film would remain fixed in place while the measurement was taken. An example of a vacuum table cross section can be seen in Figure A - 1.

[redacted]

Figure A - 1: Vacuum table cross section [A1].

The top surface of the vacuum table is the bleeder board, which is a permeable material that allows air to pass through. It is important that the vacuum pressure on the entire table is distributed evenly, which is achieved by a plenum board. A plenum board consists of a grid table with airflow channels that allow the distribution of vacuum pressure evenly. Finally, a base board is attached underneath the plenum board to provide loading support.

Different suction levels could be incorporated to account for the varying thickness of the plastic film, and thicker plastic would require more suction to remain fixed into place.

The advantages of this concept are ease of use and ease of implementation. The vacuum table would also ensure that the film is not being stretched at all, as the film would not be pulled to achieve flatness. The vacuum table would require more design time as it can be more complex than other tensioning concepts, which would increase the overall cost.

A1.2.2 Rubber Cylinder

The second concept is the use of rubber cylinders as a film tensioning device. For this application, the cylinders will be placed on two opposite edges of the table and the film will be placed in between, as shown in Figure A - 2.

Figure A - 2: Plastic film tensioning method using rubber cylinders [A2].

The cylinders would be manufactured out of rubber so that the film can adhere to the cylinder easily. The rubber cylinders can rotate, pulling the film until it is completely flat, and the cylinder would have a locking mechanism to prevent the film from unwinding.

The main advantage of this concept is that it requires minimum power. However, it would take minutes to set up the film in place before taking measurement.

A1.2.3 Weights

The next film tensioning concept uses weights. Weights will be clamped on one end of the film to provide a sufficient amount of tension. In this application, the film must be completely perpendicular to the weight to prevent the film from moving side to side. The weight required for film tensioning must also be controlled to prevent the film from stretching. An example of weights being used to tension the film can be seen in Figure A - 3.

Figure A - 3: Film tensioning concept using weights [A2].

This concept is cost efficient and only requires minimal maintenance. However, there would be a high risk of film stretching if the weight applied is not properly controlled, and it is susceptible to operator skill.

A1.3 Measurement Device Concepts

The measurement device is the most important aspect of the design. This has the largest contribution to the overall accuracy and repeatability of the design, which is the top needs as identified by the client. For this section, a laser measurement sensor, a digital caliper sensor, and an electromagnetic induction linear scale were considered.

A1.3.1 Laser Measurement

The first measurement concept is a laser sensor, as the laser sensors have a wide variety of applications they can be used in. Laser measurement sensors work on a simple principle. Light travels towards a target from the source, the light bounces off of the target, then the reflected light travels back to the source [A3]. The time of this travel is used to determine the distance from the sensor to that target. A simple equation relates the time to the distance, as follows:

$$D = C * t/2$$

In this equation, D is the distance to be measured, c is the speed of light in Earth's atmosphere, and t is the amount of time taken for the laser to return to the source. The measured time is divided by two to represent the time required to travel in one direction only.

A laser sensor would be aligned with the first eye mark pointing at a target that is positioned at the second eye mark in order to get a distance.

Laser measurement sensors are commonly used over greater distances with lower accuracy than what is required for this project's specific application. Laser sensors meeting the client's needs were found. However, these sensors lose accuracy with an increased measurement distance. The main disadvantage of this system is the precise setup that is required, and any mishandling of the device could easily cause misalignment and measurement errors.

A1.3.2 Digital Caliper

A digital caliper uses the principle of capacitance to generate its measurement, and this technology is being considered as a concept for a measurement device. The system consists of a series of rectangular plates etched into a copper or glass strip that stretches the length of the bar, usually concealed by a taped scale or simple cover. Mounted above this in the moveable jaw is a similarly plated slider board. When these rectangular boxes align and misalign, signals are sent to an electronic chip within the caliper case to generate the readings seen on the digital display [A4].

For this concept, the copper strip and slider board are integrated into a fixed beam that extends the length of the design space (1650mm). Two jaws would be allowed to travel linearly along the beam, and the jaws could be aligned to the eye marks that are being measured. This setup is shown in Figure A - 4.

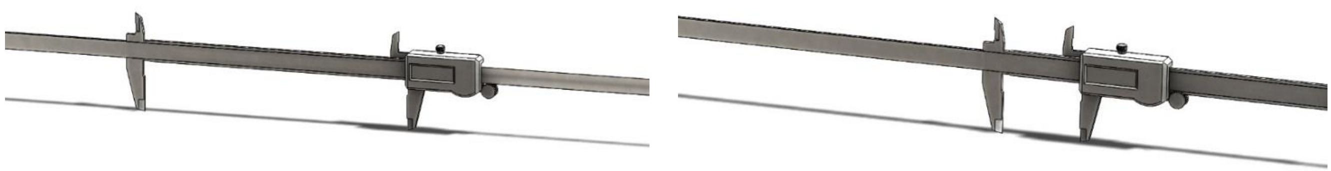

Figure A - 4: Measurement device using the principle of digital caliper.

Following are the measurement steps required for this concept. Step 1: Loosen the locking screw of the digital caliper. Step 2: Position the left jaw with the eye mark. Step 3: Move the right jaw directly beside the left jaw, and hit the “zero” button on the right jaw. Step 4: lock the left jaw in place and move the right jaw to the second eye mark, and read out the LCD display.

The design is accurate up to ± 0.03 mm, well within the project requirements. However, moisture can be a problem for digital caliper. If water gets between the stator strip and the slider board, the necessary air gap is eliminated and the signal can become noisy or nonexistent.

A1.3.3 Electromagnetic Induction

The electromagnetic induction concept uses pre-existing technology from a manufacturer called Mitutoyo™ who specialises in measurement instruments. Their line of absolute linear scales uses electromagnetic induction to generate measurements that are accurate up to 0.01mm. The device itself has a single detector head that is mounted on a linear guideway, which can move horizontally on that guideway from one end to the other, as shown in Figure A - 5.

Figure A - 5: Linear scale measurement instrument [A5].

As the detector head travels linearly, three capacitance type sub scales and one photoelectric sub scale take position readings and display the output onto a compatible digital readout (DRO) system. The sub scales use a combination of pitches that increase the accuracy of the device, shown in Figure A - 6.

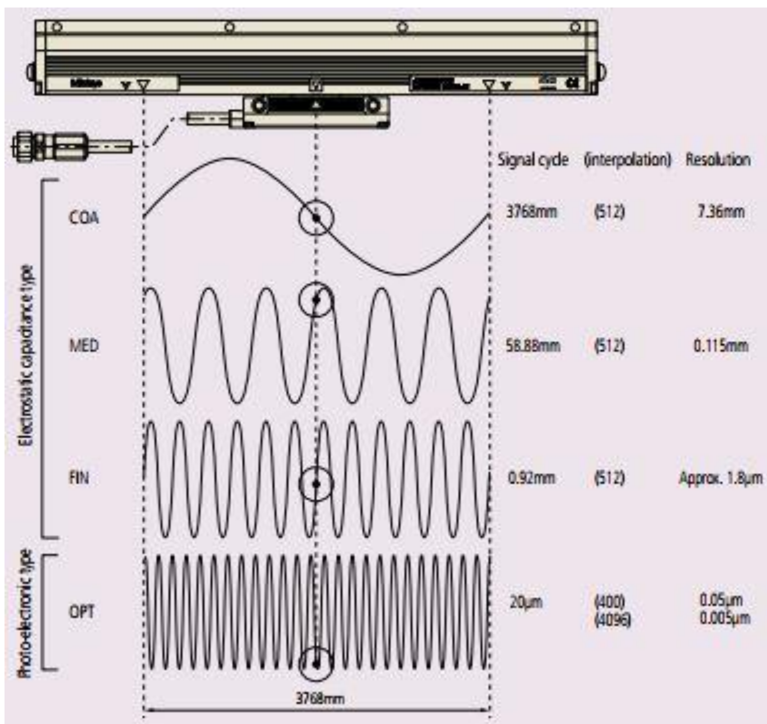

Figure A - 6: Principle of the electromagnetic induction linear scale [A6].

The figure above shows that the resolution of each capacitance type sub section increases in precision as the signal cycle decreases in size. Each of these sub sections of measurement work together to achieve the high accuracy that the linear scale possesses.

The DRO system is also capable of zeroing the system at any location, allowing for a minimal setup time for each measurement. The device is entirely enclosed and is designed for a harsh working environment, reducing the risk of damage and increasing operator safety.

The main advantage of this concept is that it is an off the shelf device with accuracy that is well within our tolerance of ± 0.5 mm.

A1.4 Eye Mark Locator Concepts

The final section is how the device will locate the eye marks once the plastic film is flat and properly tensioned. The ability to precisely locate the eye marks is critical to the success of the design, as improper alignment would affect the accuracy of the measurement.

Eye marks are often black rectangles, but can also be transparent or white. This means the locator must be able to account for these different possibilities, and an automated vision detection system will not be a viable option.

Several different methods were considered, including a magnifying glass, a projected laser line, and a triangular block. These concepts are assumed to be mounted to the measurement device at the desired measurement location.

A1.4.1 Magnifying Glass

A magnifying glass is a simple solution to help the operator line up the eye marks accurately. This concept has a magnifying glass oriented parallel to the length of the plastic film, and two alignment markers etched on the surface of the glass, shown in Figure A - 7. The alignment markers are in corners opposite to each other and are used to align with two corners of the eye mark.

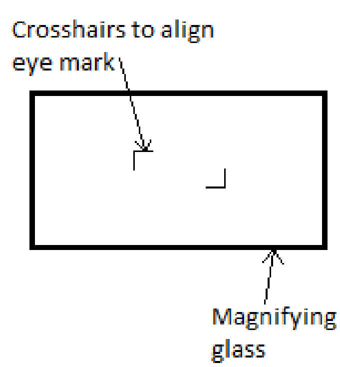

Figure A - 7: Magnifying glass concept for locating eye marks.

The magnification aspect of this concept allows increased accuracy, as the operator has enhanced vision to locate the edges of the eye mark.

The alignment corners on each side eliminate the possible source of error where the operator may measure the front edge of one eye mark and the back edge of the second eye mark, introducing measurement error. Additionally, the spherical nature of the magnifying glass would cause additional error, which should be addressed if this option were pursued.

A1.4.2 Projected Laser Line

The projected laser line concept uses a laser capable of projecting a straight line onto the plastic film, shown in Figure A - 8.

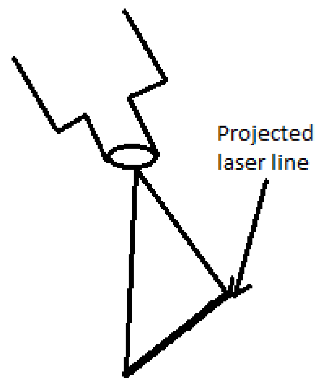

Figure A - 8: Projected laser line concept for locating eye marks.

The projection of the line would be oriented parallel to the long edge of the eye mark, or alternatively, it could be used to line up the edge of a graphic on the occasion that eye marks are not present on the film sample.

This concept can be inaccurate due to the precise angle requirement that would have to be maintained while lining up eye marks. There would also be an issue with the reflectiveness of the laser on the film.

A1.4.3 Triangular Block

The last concept for locating the eye marks is a simple extruded triangular block. The working principle of this concept is the sharp point which allows accurate placement to the edge of the eye mark, shown in Figure A - 9.

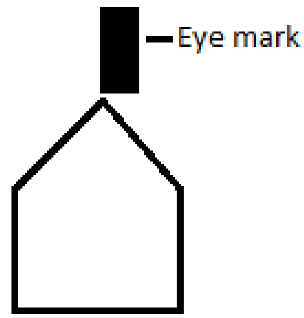

Figure A - 9: Triangular block concept for locating eye marks.

The simplicity of the design would be cost efficient, can be easily integrated onto the measurement device, and would have minimal maintenance required. The accuracy of alignment would be limited to how accurately the operator can see the line.

A2.0 Concept Analysis and Selection

In the previous section, the team presented nine design concepts for the three design components. To accurately select the optimal concept, the weights of each criteria must first be determined. This determination of the weighted criteria was then used to accurately rank each concept.

A2.1 Selection Criteria

To select the best concept for each design component, selection criteria were set out for evaluating the design concepts. The following selection criteria were deemed to be most important to the design as specified by the project needs and client input.

- Accuracy – The apparatus must meet the accuracy requirement of ± 0.5 mm
- Repeatability – The variation in measurements taken by an operator on a different film sample is minimal
- Manufacturability – Ease of manufacturing
- Setup/Operation time – Setup and operation time is as short as possible
- Ease of use – The apparatus should be simple to use during the measurement process
- Easy to maintain – The apparatus should not require long or frequent periods of maintenance, nor complex maintenance processes
- Long Lifespan – The device will remain in operation for a sufficient time period

The following criteria were not considered in the criteria weighting matrix due to lack of relevance to our specific project, and minimal impact compared to the above criteria as specified by client.

- Cost
- Environmentally safe and disposable
- Low power consumption
- Digital output to computer

A2.2 Criteria Weighting Matrix

Before scoring the selected concepts, the selection criteria were ranked and weighed. The team listed all criteria and created a matrix to determine the more important criteria. Criteria that scored the highest weight are the most important criteria in the design, whereas the criteria that had the lowest weight are the least important. TABLE A - I shows the results of the criteria weighting exercise.

TABLE A - I: SELECTION CRITERIA WEIGHTING MATRIX

		1	2	3	4	5	6	7
	Criteria	Accuracy	Repeatability	Manufacturability	Ease of use	Easy to maintain	Setup/Operation time	Long lifespan
1	Accuracy		1	1	1	1	1	1
2	Repeatability			2	2	2	6	2
3	Manufacturability				4	5	6	3
4	Ease of use					4	6	4
5	Easy to maintain						6	7
6	Setup/Operation time							6
7	Long lifespan							
	Criteria	1	2	3	4	5	6	7
	Total Hits	6	4	1	3	1	5	1
	Weightings	28%	19%	5%	14%	5%	24%	5%

The results showed that the accuracy, setup/operation time, and repeatability are the three most important criteria which score 28%, 24%, and 19% respectively. Long lifespan, easy to maintain and manufacturability are the least important criteria.

A2.3 Concept Scoring

The next step of the concept selection was scoring the three concept components that were selected. These concepts were scored based on the established weighting. Each criterion was assigned a value ranging from 1 to 5 for each concept, 1 being the lowest and 5 being the highest rating. The scores were multiplied by their weights and were summed. The final rating is based on the results of all team members' discussions and evaluations. TABLE A - II to TABLE A - IV show the final scoring for the three concept components, respectively. TABLE A - II shows the weighted scores for the three film tensioning design concepts.

The Vacuum Table was chosen as the final design with a total score of 3.61, compared to the Rubber Cylinder and Weights which received score of 1.68 and 2.96, respectively.

TABLE A - II: FILM TENSIONING CONCEPTS SCORING

	Film Tensioning Concepts						
		Vacuum Table		**Rubber Cylinder**		**Weights**	
Selection Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Accuracy	0.28	5	1.4	1	0.28	2	0.56
Repeatability	0.1	4	0.4	3	0.3	4	0.4
Manufacturability	0.1	2	0.2	2	0.2	3	0.3
Ease of use	0.19	3	0.57	1	0.19	2	0.38
Easy to maintain	0.05	3	0.15	2	0.1	3	0.15
Setup/Operation time	0.23	3	0.69	2	0.46	4	0.92
Long Lifespan	0.05	4	0.2	3	0.15	5	0.25
Total Score		3.61		1.68		2.96	
Rank		1		3		2	
Continue?		Yes		No		No	

TABLE A - III shows the weighted scores for the three measurement device design concepts. The Electromagnetic Induction received the total score of 3.98, which has a significant advantage over the Laser measurement and Digital Caliper. Therefore, the Electromagnetic Induction was chosen as the final design of the measurement device concept.

TABLE A - III: MEASUREMENT DEVICE CONCEPTS SCORING

		Measurement Device Concepts					
		Laser		**Digital Caliper**		**Electromagnetic Induction**	
Selection Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Accuracy	0.28	2	0.56	3	0.84	5	1.4
Repeatability	0.19	1	0.19	3	0.57	4	0.76
Manufacturability	0.05	2	0.1	1	0.05	2	0.1
Ease of use	0.14	2	0.28	4	0.56	5	0.7
Easy to maintain	0.05	2	0.1	3	0.15	3	0.15
Setup/Operation time	0.24	2	0.48	2	0.48	3	0.72
Long Lifespan	0.05	1	0.05	2	0.1	3	0.15
Total Score		1.76		2.75		3.98	
Rank		3		2		1	
Continue?		No		No		Yes	

TABLE A - IV shows the weighted scores for the three eye-mark locator design concepts. The Magnifying Glass received the highest score of 4.42. However, the final score of the Triangular Block concept is 4.29, which is very close to the highest score. Therefore, both Magnifying Glass and Triangular Block concept are selected for the next phase design.

TABLE A - IV: EYE MARK LOCATOR CONCEPTS SCORING

		Eye Mark Locator Concepts					
		Magnifying Glass		**Projected Laser Line**		**Triangular Block**	
Selection Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Accuracy	0.28	5	1.4	3	0.84	3	0.84
Repeatability	0.19	4	0.76	3	0.57	5	0.95
Manufacturability	0.05	2	0.1	1	0.05	4	0.2
Ease of use	0.14	4	0.56	1	0.14	5	0.7
Easy to maintain	0.05	4	0.2	2	0.1	4	0.2
Setup/Operation time	0.24	5	1.2	2	0.48	5	1.2
Long Lifespan	0.05	4	0.2	2	0.1	4	0.2
Total Score		4.42		2.28		4.29	
Rank		1		3		2	
Continue?		Yes		No		Yes	

A2.4 Recommended Design

Though the concept analysis process, it was determined that a combination of a vacuum table, an electromagnetic induction linear scale, and the magnifying glass/triangular block was the best combination of concepts. Client feedback on the design affirmed that this is the design that should be further pursued and optimized, therefore no additional screening or sensitivity analysis was performed. Further recommendations for the final design include a grid pattern on the vacuum table for increased alignment, incorporating a second degree of freedom on the measurement device for reduced setup time, and an anti-static material that could be used to help aid in the flattening of the plastic film as it is placed on the vacuum table.

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[A4] TresnaInstruments, "Absolute mode digital caliper," TresnaInstruments, n/d. [Online]. Available: http://www.tresnainstrument.com/product/ec06.html. [Accessed 23 Oct 2017].

[A5] Mitutoyo, "Ecatalogue Mitutoyo," n/d. [Online]. Available: http://ecatalog.mitutoyo.com/cmimages/002/267/AT103.jpg. [Accessed 23 Oct 2017].

[A6] "Digital scale and DRO systems", Mitutoyo, 2017. [Online]. Available: http://www.mitutoyo.com/wp-content/uploads/2015/04/H-Section-US-1003.pdf. [Accessed: 25- Oct- 2017].

Appendix B – Analysis Methods and Results

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B1.0 Prototyping Verification

A test analysis was performed for this project to validate any designed solutions and potential concerns regarding the measuring process. A prototype vacuum table with linear scale was made for simulating the measuring procedure using the designed measuring product.

A list of objectives was identified for the test analysis which was based from the team's concerns during the design optimization process. The list of test objectives is shown as follows:

- To see if the vacuum table causes the film to form dimples on the table surface
- To measure the comfortable distance between the operator and the point of measurement
- To determine if the linear sensor will hinder film placement when in the lowered position
- To estimate the duration of the whole process

B1.1 Test Conditions

Some test conditions were considered before conducting a test analysis. The prototype was made to mimic the designed measuring device. The prototype made for the test analysis came from household and crafting materials. The materials used for making the prototype were relatively inexpensive compared to the designed product.

A hockey table was used as a prototype because it has a hole pattern that is similar to the vacuum table. A household vacuum cleaner is attached to the hockey table to provide a vacuum force to hold the film in place.

The material used to simulate a raising mechanism and linear scale is made of craft board. The length of the craft board can be easily adjusted according to the desired distance from the body and the point of measurement. The craft board bracket is pinned tightly on the side of the hockey table. The tight pin on the bracket simulates as a friction hinge from the actual design. A long piece of craft board is attached to the two brackets across the hockey table to simulate a linear scale that is attached to the bracket.

A plastic film sample from Winpak was used for test analysis to simulate the actual film measuring procedure.

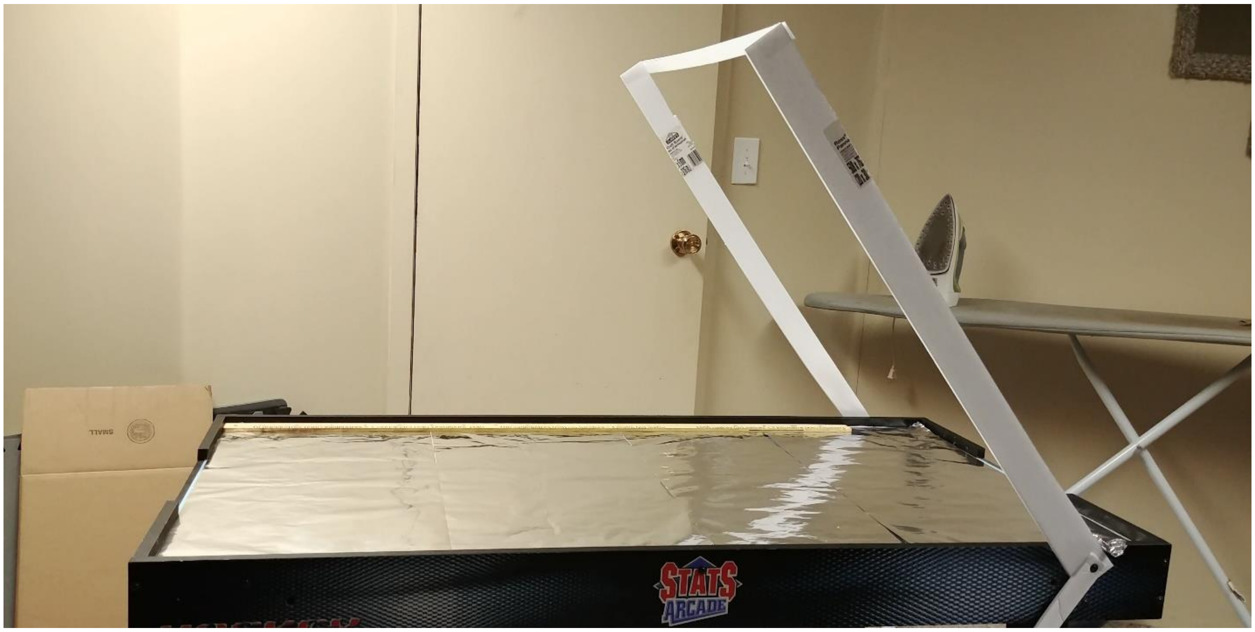

Figure B - 1: Prototype setup of vacuum table and linear sensor mechanism.

B1.2 Test Possibilities

The size of the hockey table is one-third of the actual vacuum table design. This would affect the duration of the measurement procedure as the measurement distance separating the eye marks is relatively short compared to the actual working setup of the design.

The vacuum power from the vacuum cleaner cannot be controlled and is not as strong as the actual vacuum pump motor. This would affect the dimple effect of the film on the measurement surface.

B1.3 Test Techniques

The whole testing process was recorded from a video recorder. The video taken displays the duration of the measuring process and was verified by the design team.

The simulated bracket was cut up to a desired length and the distance was measured from the front edge of the table and the linear scale.

The simulated linear scale was raised up to a certain angle in order to lay down and move the plastic film in place. The angle of inclination of the bracket is determined by measuring the height of the linear scale to table surface and the horizontal distance of the linear scale to the simulated hinge.

B1.4 Test Data

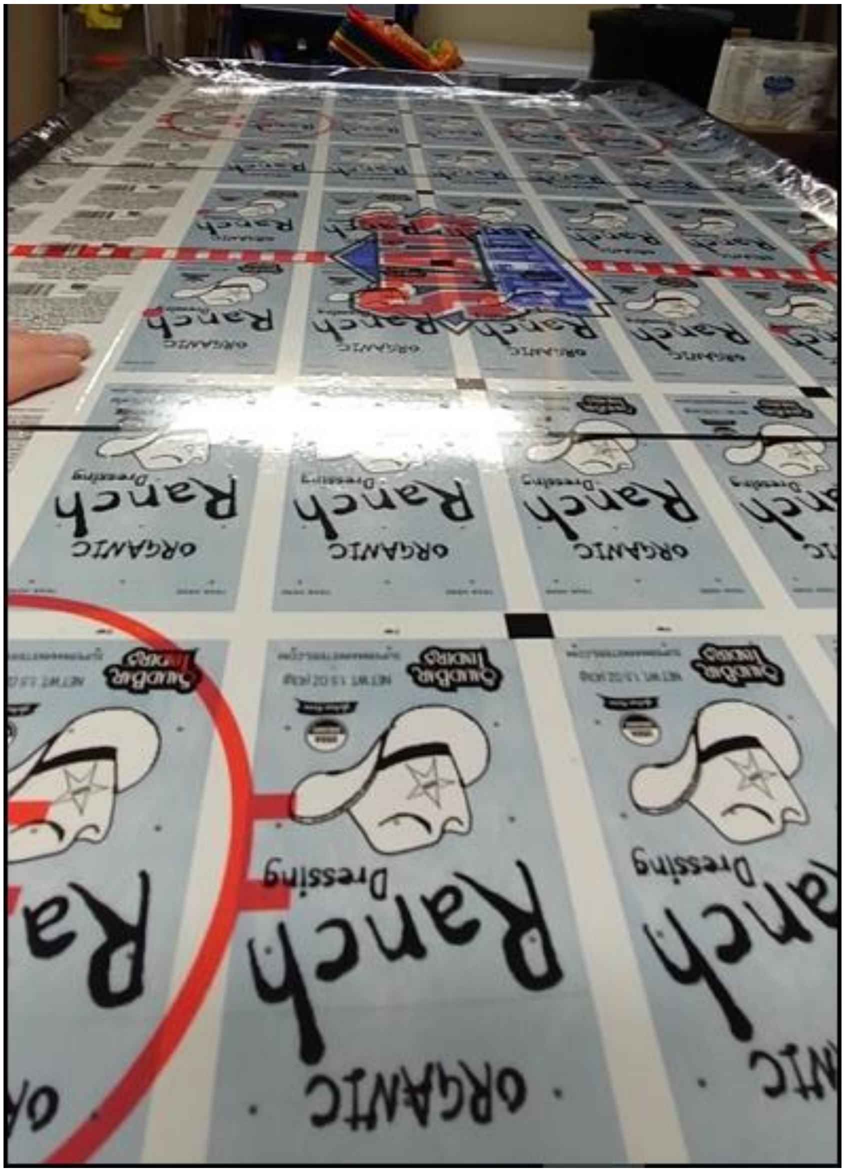

Figure B - 2: Film laid down on the simulated vacuum table.

The film on the simulated vacuum table was laid down flat and did not cause any dimples on the film.

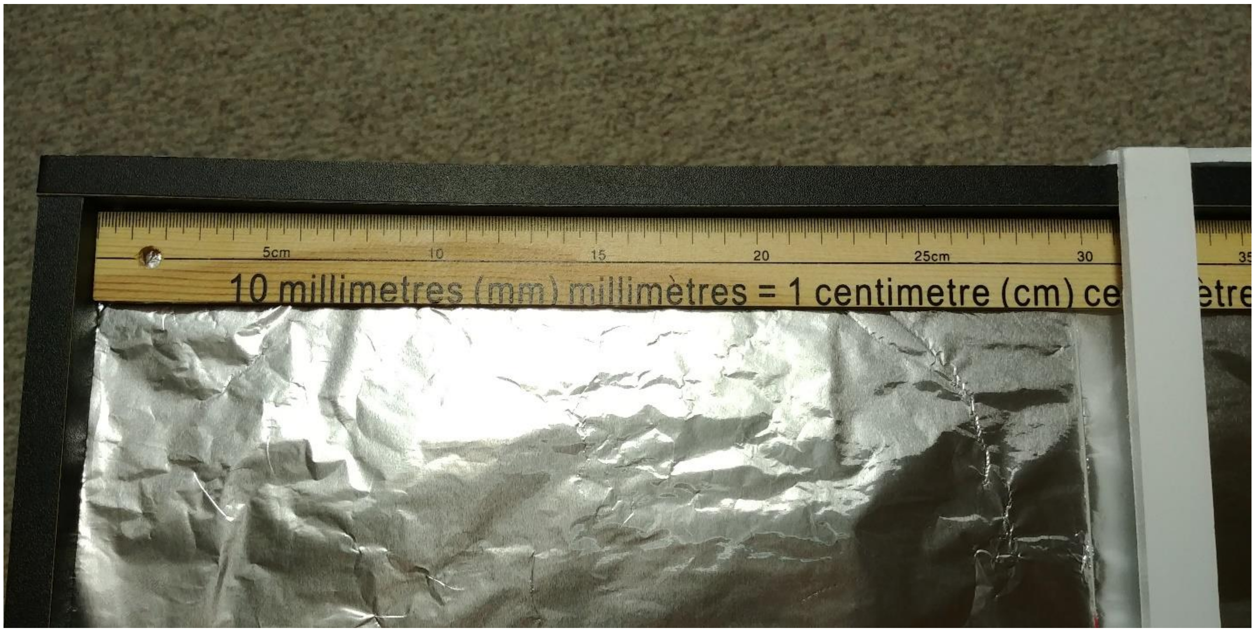

Figure B - 3: Distance from front edge to linear scale.

The length of the bracket was adjusted to a comfortable distance from the front edge of the table and was measured. The comfortable distance between the operator and the linear scale was found to be 310 mm for an operator of height 5’6”.

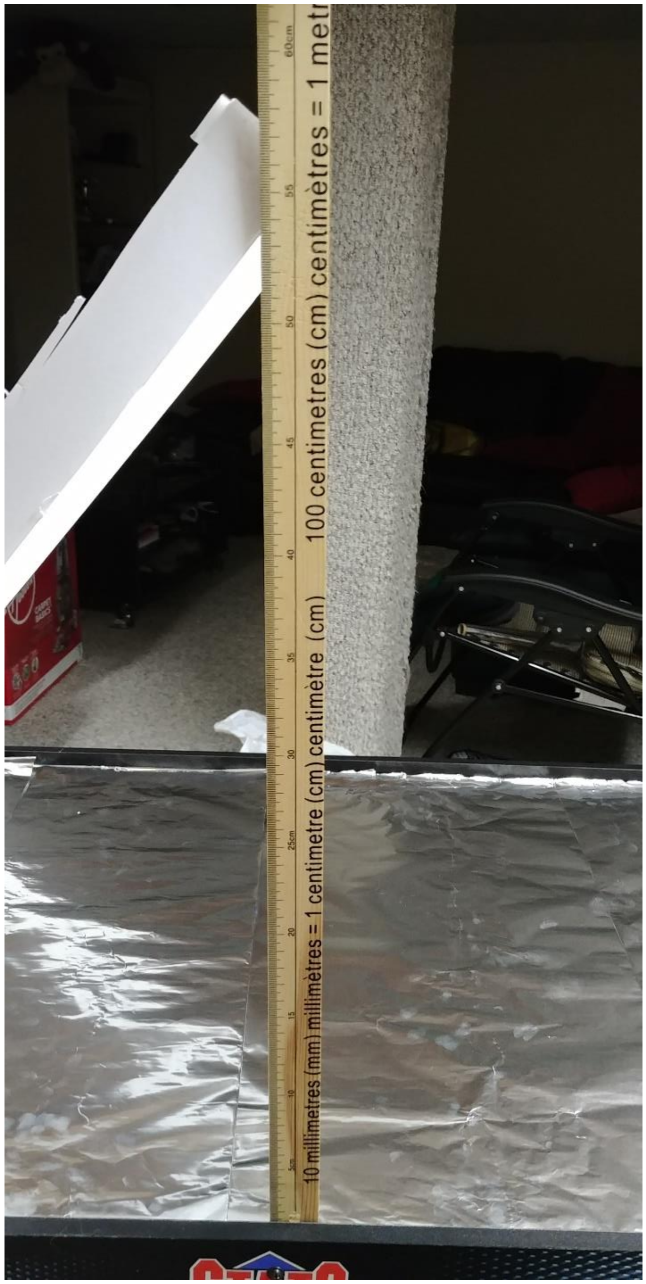

Figure B - 4: Distance from table surface to linear scale.

The raising mechanism was adjusted to a certain height and did not cause any obstruction while laying down the film on the table surface. The height of the linear scale from the table surface was 550 mm.

The duration from the video taken while performing a measuring procedure was about 90 seconds.

B1.5 Prototyping Conclusion

In the test analysis, all the objectives were met. The results from this test provided a general idea and clarification of the potential concern for the final design. From this test, one can conclude that the film will not cause dimples on the table surface. The comfortable distance measured between the front edge of the table and the point of measurement is 310 mm. This value will only provide a general distance for the final design, as there are multiple factors that could change the comfortable distance such as height of the operator, height of the table and inclination of the table with respect to the ground. The measuring process was performed and the operator did not encounter any discomfort or obstruction while raising up the linear scale and laying down the plastic film. From the simulated measuring process, the distance between eye marks was measured three times in three different locations. The duration of the simulated measuring procedure was 90 seconds, which is less than the maximum duration of 120 seconds. To conclude, the data from the test analysis shows that the concept of the final design has potential to function effectively in the real operation environment.

B2.0 Hinge Force Analysis

Data obtained from the completed Solidworks files are as found in TABLE B - 1. These are the final specifications of the components supported by the hinge.

TABLE B - 1: HINGE SUPPORTED COMPONENT SPECIFICATIONS

Part	Quantity	Weight	Distance from Hinge centre
Linear Sensor	1	2.300 kg	0.508 m
L bracket	1	0.976 kg	0.508 m
Hinge Mount	2	1.620 kg	0.2448 m
Block	2	0.010 kg	0.508 m

From TABLE B - 1, one can find the data used to determine the torque requirements for the hinge. This calculation is shown below to demonstrate the process used to source torque hinges in the final design.

The weight of each part is used with gravity to determine the force acting downwards on the part. To create a minimum expectation for the hinge, the parts are all assumed to be located

0.550 m away from the hinge. This will allow confidence when sourcing a hinge as the actual operation of the device will not have as much weight located as far from the centre of rotation. This calculation can be found below, which will show an exaggerated torque acting on the hinges.

$$(2.3 + 0.976 + 2 * 1.62 + 2 * 0.01)kg * \frac{9.81m}{s^2} * 0.55m = 35.265\ Nm$$

$$\frac{35.265}{4} = 8.816\ Nm/hinge$$

Due to the correct orientation of the components supported by the hinges being closer than in the above calculations, this is not a realistic number. A more accurate calculation follows using the exact weights and distances from the hinge centre of rotation, found in TABLE B - I. This calculation determines the actual torque acting on each hinge.

$$(2.3 + 0.976 + 2 * .01)\ kg * 9.81\ \frac{m}{s^2} * 0.508\ m = 16.426\ Nm$$

$$(2 * 1.62)\ kg * 9.81 \frac{m}{s^2} * 0.2448\ m = 7.781\ Nm$$

$$(16.426 + 7.781)\ Nm = 24.207\ Nm$$

$$\frac{24.207\ Nm}{4\ Hinges} = 6.05 \frac{Nm}{Hinge}$$

6.05 Nm is the real torque felt by each hinge and shows that each hinge allows a buffer of 3 Nm. This serves to increase the longevity of the hinges and proves the design of the raising mechanism will not fail.

Appendix C - Quotes and Pricing

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C1.0 Vacuum Table Quote

VACUUMTABLES.COM

4321 N. Knox Avenue
Chicago, IL 60641-1906 USA
www.vacuumtables.com

VacuumTables.com
A division of Graphic Parts International, Inc.

Phone: 773.725.4900
Fax: 773.777.0909
sales@vacuumtables.com

December 3, 2017

Page 1 of 5

QUOTATION PROPOSAL # GPI57362

Aru
R Jorel Nepomuceno

Winnipeg, MB , Canada
E-mail:

Phone: Fax:
Attn: Aru Ryuzaki
From: Michael Green

GPI ALUMINUM VACUUM TABLE
WITH ALUMINUM HONEYCOMB

Qty	*Catalog No.*	*Description*	*Price*
1	VBAH-1141-GPI	1-1/4" Vacuum Table W/Aluminum Honeycomb	$1,690.00
1	VBSF1-GPI	Solid Outside Table Framing	Included
1	VBTBP-GPI	Vacuum Table Top and Bottom to be Parallel	Included
1	CR-195	Crating, Banding & Padding To Help Prevent Damage	$195.00

NOTE: This table is not to be used with coolants

Table Specifications:

- OUTSIDE Table Dimension: 71” x 33-1/2” (180 x 85 mm)
- Vacuum Hold-down Area: 67” x 31-1/2” (170 x 80 mm)
- Table Overall Thickness 1-1/4" (31.75 mm) (Other Thicknesses Available)
- Vacuum Table Top Vacuum Holes Position: 3/4" Center To Center (CNC Drilled W/Hole Dia. .054")(1.37mm)
- Table Surface: Clear Anodized Aluminum (1/8")(.125" or 3.175 mm)
- Table Bottom: Aluminum (1/8")(.125" or 3.175 mm)
- Number Of Ports/Air: 1 Port Diameter Is 1-1/2"O.D.

Note: Ports must be at least 1/4" (6.35mm) smaller than vacuum table height; if applied to table edge

Standard Features:

- Non-Rusting, Non-Oxidizing, Anti-Static & Warp Resistant Thick Top Plate
- Inside: Heavy Duty Celled Aluminum Honeycomb For Proper Support & Air Flow
- Port Location on the table will be centered on table bottom, unless otherwise specified

Your Complete Manufacturing Source for Screen Printing Equipment & Supplies
Formerly Advance World Trade

Figure C - 1: Vacuum table quote (page 1).

VACUUMTABLES.COM

4321 N. Knox Avenue
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www.vacuumtables.com

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Phone: 773.725.4900
Fax: 773.777.0909
sales@vacuumtables.com

December 3, 2017 Page 2 of 5

Vacuum Table Flatness

We take pride in the fact we can manufacture the "FLATTEST" vacuum table in the world. Flatness is measured in many ways and varies depending on how you measure.

Please inquire about your table use if not under these exact conditions. Vacuum tables can deflect or bend depending on how you use and support them.

We have high level engineers that can help you in your design to reduce or eliminate deflection or other issues that may arise in your application.

When we ship our tables, tolerances are as follows:

Flatness is .007" (.18mm) or better, over 36" (91cm), for vacuum table flatness up to 7 feet (214cm) wide x 10 feet (305cm) long as measured on a flat, solid surface. For better tolerances, please inquire.

Our standard tolerances are measured using precise CNC machine accuracies on a full, solid, machined flat surface. If you are using your vacuum table under different conditions, the flatness measurements may and could vary.

Our flatness guarantee represents flatness measured prior to your installation or work performed on the table. For better tolerences, please inquire.

OPTIONS:

Qty	*Catalog No.*	*Description*	*Price*
	VBAFPE-GPI	Air flow ports mounted on edge of vacuum bed (per drawing)	Per Quote
	VBTPH-GPI	Threaded Port Holes	Per Quote
	VBLP-GPI	Lift Pins In Vacuum Table (Positioned Per Drawing)	Per Quote
	VBRRGI-GPI	Round Registration Guides For Vacuum Table (Positioned Per Drawing)	Per Quote
	VBSRGI-GPI	Square Registration Guides For Vacuum Table	Per Quote
	VBZ-GPI	Table Air Flow Zones. Number of zones: ________ per customer drawing	Per Quote
	VBTI-GPI	Threaded Mounting Inserts (Positioned and drilled Per Drawing)(with inside steel blocks from table bottom) **NOTE:** ***These holes can be used to mount table down to support base underneath***	Per Quote
	VBCB-GPI	Counter Bore Through Holes in Table Top to mount table to base. Please provide location drawing.	Per Quote
	VBTH-GPI	Threaded Holes Into Solid Table Frames	Per Quote
	VBSST-GPI	Stainless Steel Top for Vacuum Table	Per Quote
	VBMISC-GPI	Misc. Charges For Vacuum Tables	Per Quote

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Figure C - 2: Vacuum table quote (page 2).

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sales@vacuumtables.com

December 3, 2017 Page 3 of 5

AIR FLOW SYSTEMS, FLOW ADJUSTMENT, VACUUM MOTORS, HOSES & CLAMPS, ETC.

IMPORTANT:

The size of the vacuum pump you need depends on side pressure needed, the thickness of the sacrificial board (if used) and how flat the part is to be held down. Smaller blowers may have a small difference in price. Based on your description of use, will determine if what the right size should be. If the blower is too large or small, you can exchange it for the right size.
Additionally, different size blowers may also need different size hoses, clamps, ports and valves.

You will be responsible for the freight cost both ways. The blower must be returned in its original condition and original box that it was shipped in, within 45 days. You must first obtain a return authorization from our customer service department.

CAUTION! ***If pump is used in a wet environment, DO NOT allow liquids to get to the pump. The pump warrantee will be voided!***

Blowers can only be exchanged and not returned. We will credit you the price difference if you use a smaller blower or charge you the extra for a larger blower.

The vacuum pumps we recommend are as close as possible to your requirements. You may need a larger vacuum pump if more side pressure is required.

Qty	*Catalog No.*	*Description*		*Price*
1	GPI-VM32-150	Max-Air Quiet Brushless Vacuum Motor 1/3 HP, 110-115/220-230V, 1PH 50/60 HZ, 3.0-3.6/1.5-1.8 Amps, 1.5" Port O.D		$ 710.00
1	AFV150-BVGPI	On / Off Air Flow Ball Valve with 1.5" (3.81 cm) In/Out O.D. Port		$ 145.00
25 ft	GPIH115HDE	Vacuum Hose 1-1/2" I.D. Heavy Duty Grey flexible hose.	$5.50/foot	$137.50
4 ea	GPIHC114134	Vacuum Hose Clamp 1-1/4 - 1-3/4" (32-44 mm) in Diameter	$9.35/each	$37.40
1	GPIAFV-15	Adjustment bleeder valve to adjust air flow to holes in vacuum table 1-1/2" port		$ 295.00

NOTE: this optional bleeder value will reduce or eliminate puckering of your thin stock to each vacuum hole.

NOTE: Your vacuum table quote is going to be produced for your specific requirements. Make sure all details are documented in this quote or on your order. Once you sign off on the documents, GPI takes no responsibility for any information not provided or agreed to in writing, to GPI, prior to production.
<u>SPECIAL NOTE ON TABLE FLATNESS CHECKS</u>
We will check for flatness prior to each shipment and provide you with proper reports showing all details. To do this properly so you can compare once you receive the table systems, we will need to replicate the setup at our factory so we are measuring the table flatness under the same conditions here that you are at your final location.

When you receive the tables, you then will be measuring the same way for flatness. Please provide details.

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Figure C - 3: Vacuum table quote (page 3).

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Fax: 773.777.0909
sales@vacuumtables.com

December 3, 2017

G.P.I. Guarantee, Limitations & Exclusions:

To better serve its customers, GPI, is committed to deliver as it did for decades, high quality products based on either its own design or on its customers' design. In order to keep GPI's customers satisfied with its high quality standards and avoid any misinterpretations, GPI will manufacture products and provide services to meet or, in most cases, to exceed the customers' expectations.

GPI will not be responsible for any consequences resulting from any use of the product going beyond the limits requested or specified on the purchase orders or on the customers' drawings on tables currently being quoted IN WRITING ONLY!

A table made to specific parameters such as speed, pressure, loads, etc., will lose its GPI guarantee when it is used beyond the scope of the customers' purchase order, written request, per order, customers' and/or GPI's design or the application for which the table was designed.

1. GPI will provide inspection and flatness reports on vacuum tables upon request of customer.
2. It is the customer's responsibility to check all manufactured table parameters against their designs, before the table ships from our plant or within 15 days upon receipt.
3. GPI tables have a limit to pressure applied to the tables before they crush or bend. We will not guarantee this limit. We will provide all details you may require and recommend, with your input a different style table when using higher pressure loads.
4. Each table can deflect without proper support under them. GPI takes no responsibility if you are not supporting the table properly.
5. Excessive heat may affect these vacuum tables. GPI will not take any responsibility if heat is applied.
6. GPI will provide technical support to all of its customers and guarantee all of its products.

NOTE: ***SYSTEM WILL NOT WORK IF YOU HAVE AIR LEAKS. NO AIR LEAKS ARE REQUIRED FOR FULL PRESSURE TO HOLD PART DOWN***

- ***CAUTION!*** **If pump is used in a wet environment, DO NOT allow liquids to get to the pump. The pump warrantee will be voided!**
- **These vacuum tables quoted are not used for heavy vertical or lateral loads and are not manufactured to be used where you may be applying a large amount of pressure downward onto the table surface, like for laminating or other types of said uses, or to cut into the table top. GPI offers other lines of vacuum tables for specialized uses such as pressure or other applications. You WILL destroy these tables under certain uses. Please call your GPI sales team for additional information.**
- **These vacuum tables quoted per your drawings are limited to the information which you provided per each order.**
- **If the table/system quoted was a submitted design by your company, GPI will take no responsibility for its technical operation. We can only offer input if you need. We offer engineering development work at an extra cost.**
- **100% of vacuum holes/vacuum area must be covered for full vacuum, and part must be flat.**

These tables are made to order. Once started, the order is non-cancelable.

Customer's application and system use, as described by the customer: To hold thin film flat in place

Figure C - 4: Vacuum table quote (page 4).

VACUUMTABLES.COM

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Chicago, IL 60641-1906 USA
www.vacuumtables.com

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Phone: 773.725.4900
Fax: 773.777.0909
sales@vacuumtables.com

December 3, 2017

Total Order Ex Factory Chicago: $3,209.90

Quotation Proposal Valid For 30 Days

Manufacture Time: 3-4 Weeks - After receipt of deposit.

FOB Chicago, Illinois 60641

All Delivery Dates Are Subject To Change

Terms: 50% down, balance before shipping.

Michael Green
National Sales Manager

Customer Approval ______________________________________ Date ________________

Print Name ____________________________________

Figure C - 5: Vacuum table quote (page 5).

C2.0 Linear Scale Quote

QUOTATION

THOMAS SKINNER
13880 Vulcan Way, Richmond
BC, V6V 1K6, Canada
Tel. (604) 276-2131
Fax (604) 276-8545
http://www.tskinner.com
e-mail: tss@tskinner.com

THIS QUOTATION
IS VALID FOR 30 DAYS
FROM THE QUOTE DATE

QUOTATION NUMBER	
1862077	
QUOTE DATE	PAGE
11/9/2017 11:22:58	1 of 1

Bill To:
UNIVERSITY OF MANITOBA-DEPT. MECHANICAL MFG.
E2-327 ENGINEERING INFO.&TECH. COMPLEX
75A CHANCELLOR'S CIRCLE
WINNIPEG, MB R3T 5V6

1-204-474-9688

Ship To:
UNIVERSITY OF MANITOBA-DEPT. MECHANICAL MFG.
E2-327 ENGINEERING INFO.&TECH. COMPLEX
75A CHANCELLOR'S CIRCLE
WINNIPEG, MB R3T 5V6

Customer ID: 112692

Purchase Order Number	*Ship Route*	*Customer Service Contact*
JON		JDILK

Quantities *Ordered*	*UOM* *Unit Size*	*Item ID* *Item Description*	*Pricing UOM* *Unit Size*	*Unit Price*	*Extended Price*
1.00	EA 1.0	MTI-174183A COUNTER 2-AXIS LINEAR KA-200	EA 1.0	581.09	581.09
		Order Line Notes: 3 TO 5 BUSINESS DAYS			
1.00	EA 1.0	MTI-539824 LINEAR SCALE 68/1700MM AT715 (D)	EA 1.0	794.83	794.83
		Order Line Notes: 3 TO 5 BUSINESS DAYS			

Total Lines: 2

SUB-TOTAL:	1,375.92
TAX:	178.87
QUOTE TOTAL:	**1,554.79**
	Canadian Dollar

!!QUOTATION ONLY!!

Figure C - 6: Linear scale quote.

SmartCable™ USB with Keyboard Output for Mitutoyo MIG-4A Digimatic/RS-232 Interface Unit

Price: $219.00
SKU: 600-22-MIG4A-KB-USB
Availability: Usually ships in 5 days
Quantity: 1
Add To Cart

Figure C - 7: Computer output cable quote (optional).

C3.0 McMaster-Carr

1		18-8 Stainless Steel Hex Nut M6 x 1 mm Thread 91828A251	1 Pack of 100 each	$8.73 Pack	$8.73
2		18-8 Stainless Steel Hex Head Screw M6 x 1 mm Thread, 16 mm Long 91287A136	1 Pack of 50 each	8.07 Pack	8.07
3		18-8 Stainless Steel Phillips Rounded Head Screws M4 x 0.7 mm Thread, 5 mm Long 92000A215	1 Pack of 100 each	6.51 Pack	6.51

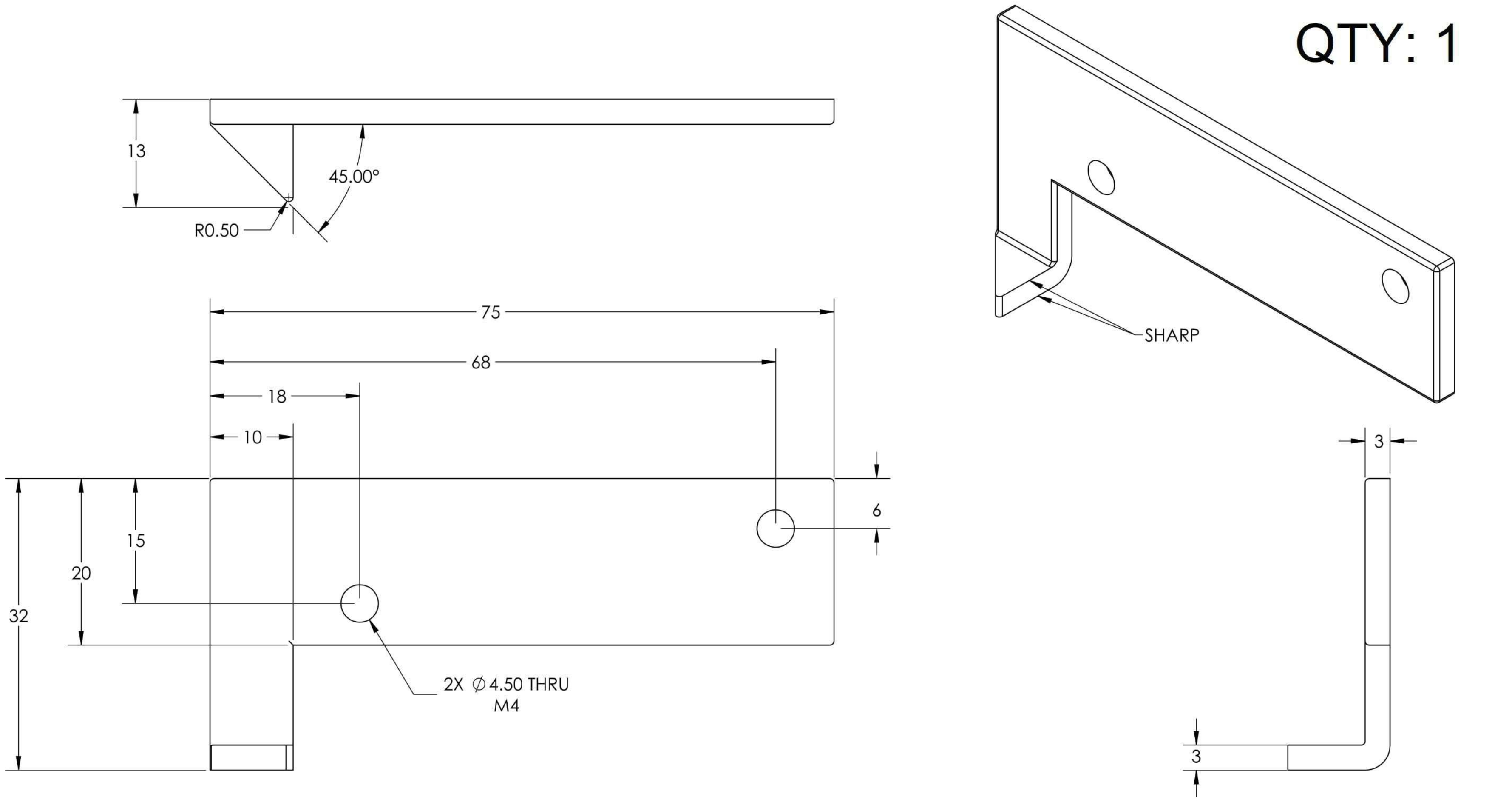
Figure C - 8: McMaster-Carr quote.

C4.0 Metal Supermarket

ALUMINUM ANGLE 6061T6 (ALUMINUM 6061T6 ANGLE 1.250 X 1.250 X 0.125) **Sku:** AA6061/11418	78.74	Inches	1	CDN$33.66
		Weight: 3 LBS Per piece price: CDN$33.66	Update Price	Delete
Click here to Add more of this product	**Comments:**			

Figure C - 9: Metal supermarket quote

Appendix D – Engineering Drawings



REV	DATE Y/M/D	DESCRIPTION	
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE

CHAMFERS N/A
FILLETS R0.5±0.1
BREAK SHARP
SHARP

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR; INTERNAL THREADS AT ∅MINOR

EDUCATIONAL AND PROPRIETARY
THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND **NOT FOR FABRICATION**. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.

MATERIAL: STEEL

FINISH: INDICATE PLATING/COATING/ETC.

DO NOT SCALE DRAWING

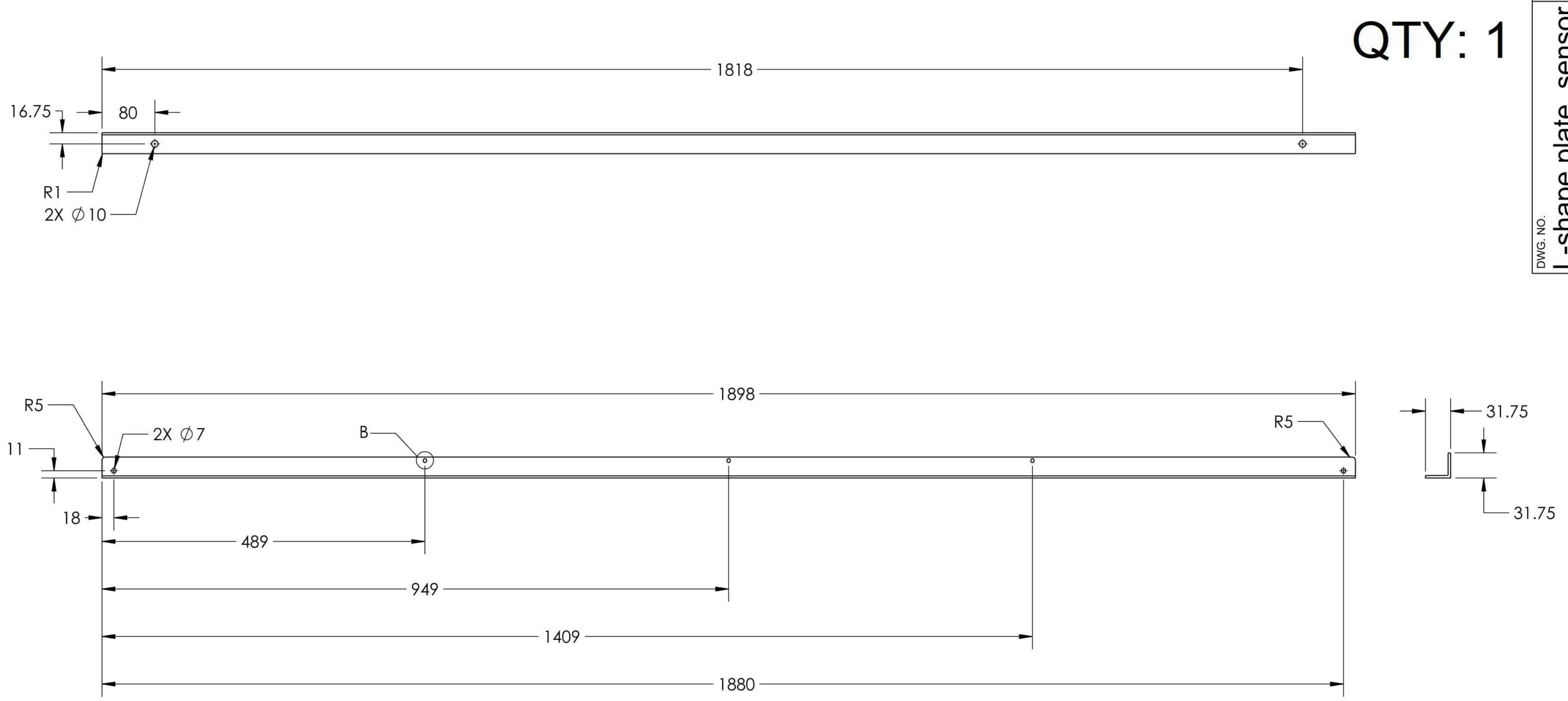
UNIVERSITY OF MANITOBA — MECH 4860 - TEAM18

TITLE: EYEMARK LOCATOR

SIZE: **B** | DWG. NO. Eyemark Locator V1.0 | REV 0

SCALE: 2:1 | WEIGHT: N/A | SHEET 1 OF 1

DWG. NO. Eyemark Locator V1.0 | REV 0



			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
REV	DATE Y/M/D	DESCRIPTION	

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE

CHAMFERS
FILLETS R1
BREAK SHARP
SHARP

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR INTERNAL THREADS AT ∅MINOR

EDUCATIONAL AND PROPRIETARY
THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND **NOT FOR FABRICATION**. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.

MATERIAL
STEEL

FINISH ???

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860 - TEAM 18

TITLE:

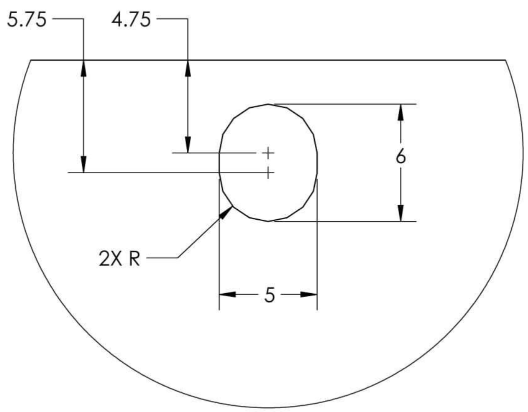
LINEAR SCALE L-SHAPE SUPPORT

SIZE	DWG. NO.	REV
B	L-shape plate_sensor	0

SCALE: 1:6 | WEIGHT: N/A | SHEET 1 OF 2

DWG. NO. L-shape plate_sensor REV 0

QTY: 1



3X DETAIL B
SCALE 4 : 1

REV	DATE Y/M/D	DESCRIPTION	
			DWN / CKD
			DWN / CKD
			DWN / CKD
			DWN / CKD
			DWN / CKD

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE

THREADED FEATURES EXTERNAL THREADS AT ØMAJOR, INTERNAL THREADS AT ØMINOR

CHAMFERS
FILLETS
BREAK SHARP
SHARP

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

EDUCATIONAL AND PROPRIETARY
THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND **NOT FOR FABRICATION**. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.

MATERIAL: STEEL

FINISH: ???

DO NOT SCALE DRAWING

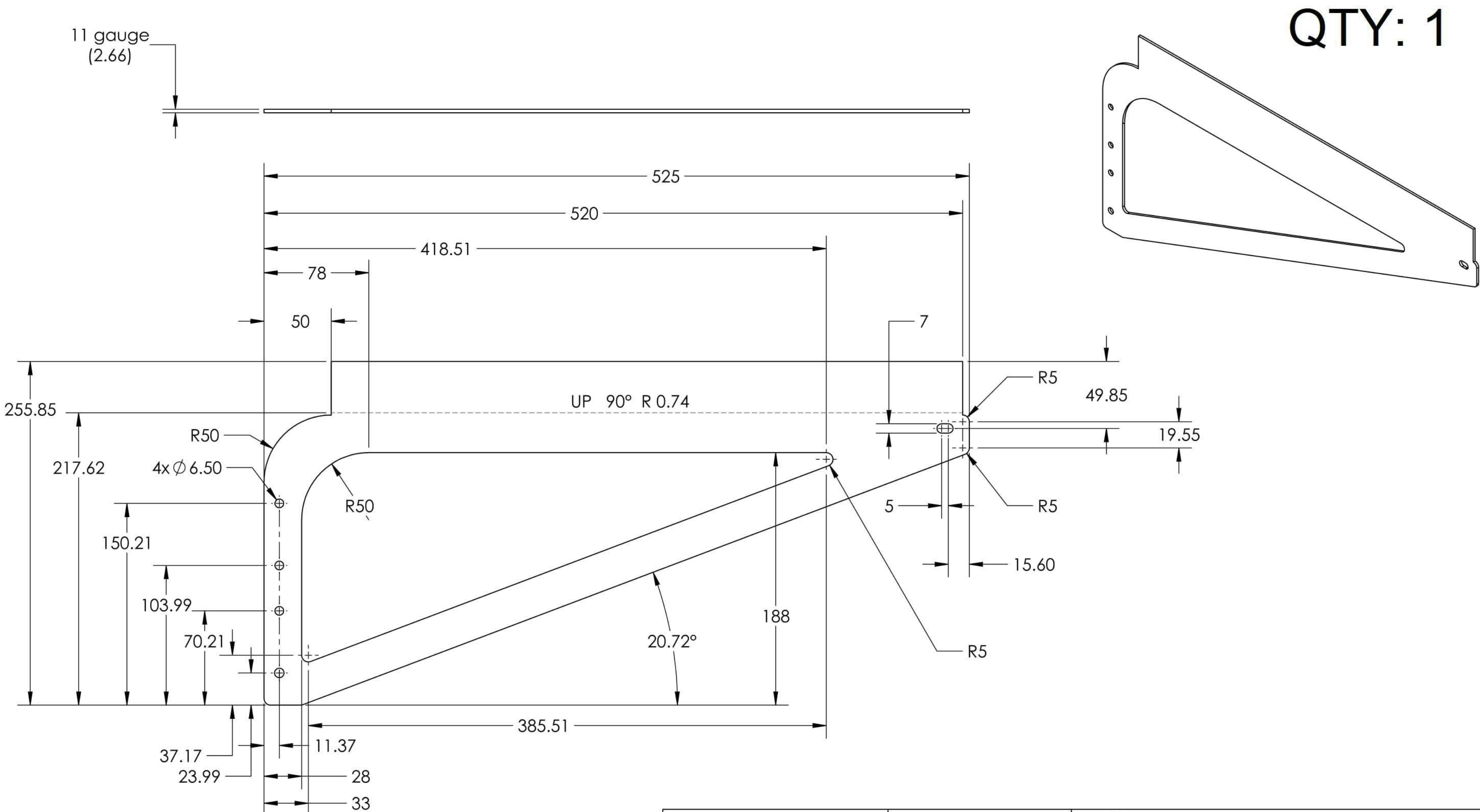
UNIVERSITY OF MANITOBA — MECH 4860 -

TITLE: LINEAR SCALE L-SHAPE SUPPORT

SIZE	DWG. NO.	REV
B	L-shape plate_sensor	0

SCALE: 1:6 | WEIGHT: N/A | SHEET 2 OF 2

DWG. NO. L-shape plate_sensor REV 0



DWG. NO. Sheet Metal Bracket V1.0 REV 0

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

FILLETS: R5 +/- 0.5

MATERIAL STEEL

FINISH ??? INDICATE PLATING/COATING/ETC.

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

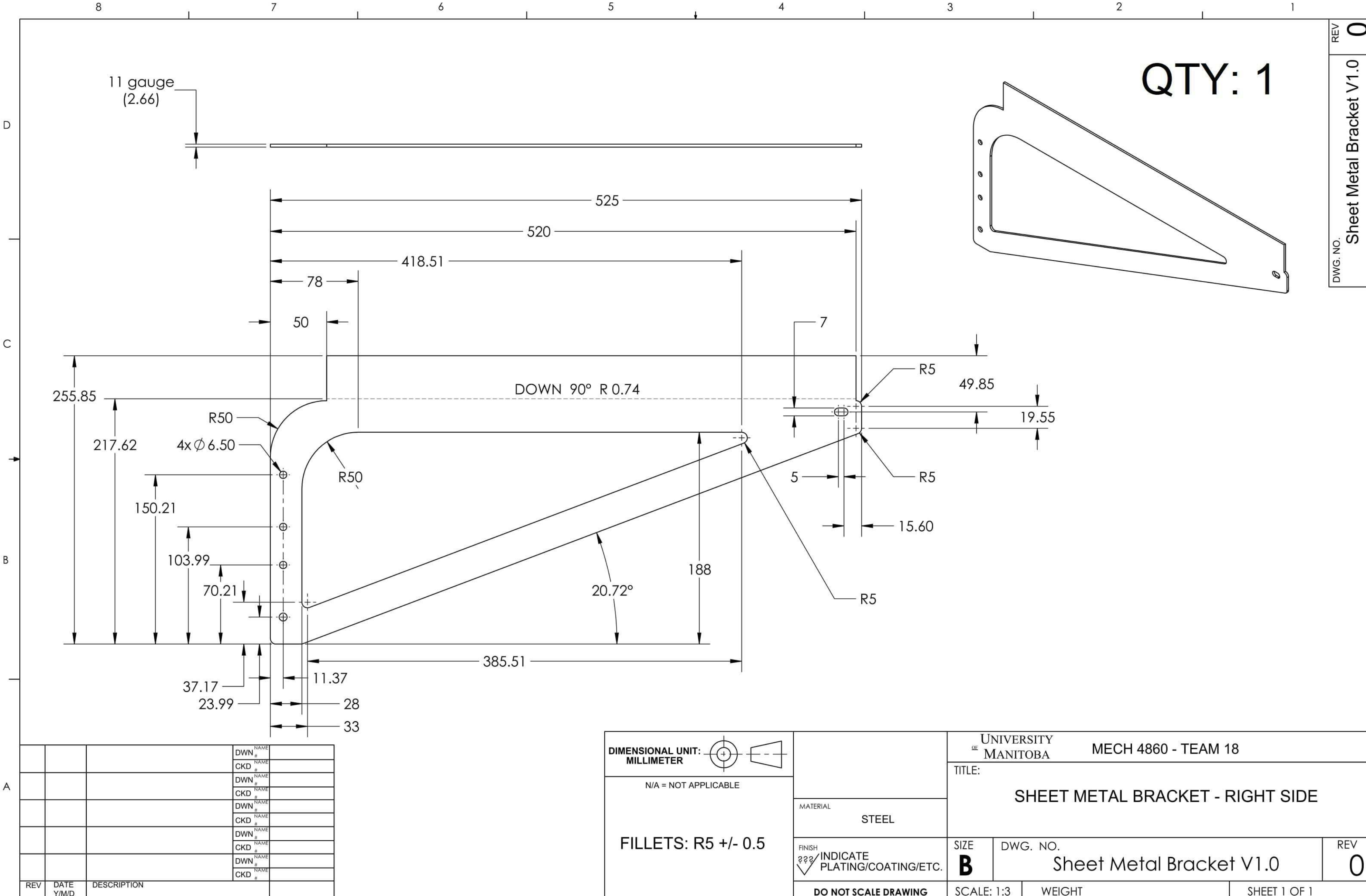
MECH 4860 - TEAM 18

TITLE: SHEET METAL BRACKET - LEFT SIDE

SIZE	DWG. NO.	REV
B	Sheet Metal Bracket V1.0	0

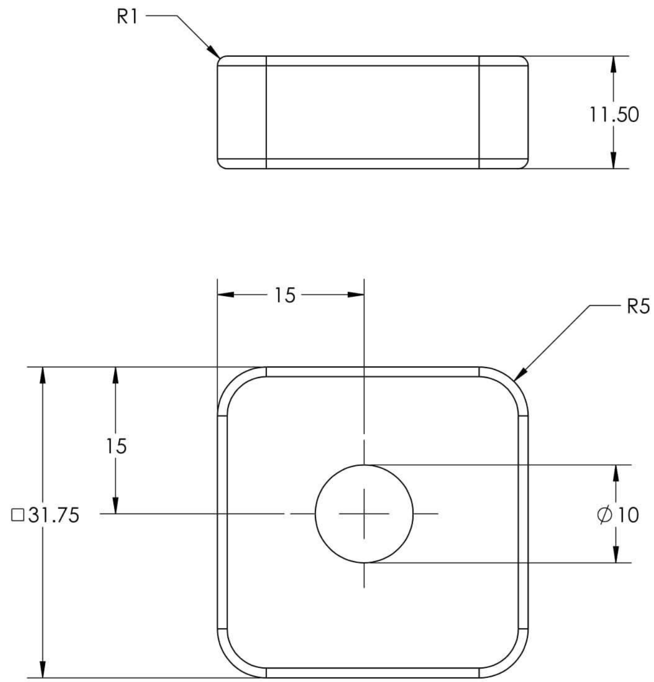
SCALE: 1:3 | WEIGHT | SHEET 1 OF 1

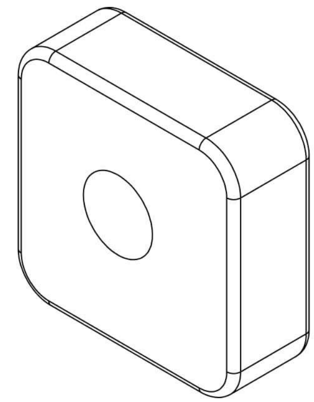
REV	DATE Y/M/D	DESCRIPTION	
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #
			DWN NAME #
			CKD NAME #



QTY: 1
11 gauge (2.66)
525
520
418.51
78
50
7
R5
49.85
19.55
DOWN 90° R 0.74
255.85
217.62
R50
4x ∅ 6.50
R50
5
R5
15.60
150.21
103.99
70.21
188
20.72°
R5
385.51
37.17
23.99
11.37
28
33
DIMENSIONAL UNIT: MILLIMETER
N/A = NOT APPLICABLE
FILLETS: R5 +/- 0.5
MATERIAL
STEEL
FINISH
INDICATE PLATING/COATING/ETC.
DO NOT SCALE DRAWING
UNIVERSITY OF MANITOBA
MECH 4860 - TEAM 18
TITLE:
SHEET METAL BRACKET - RIGHT SIDE
SIZE B
DWG. NO.
Sheet Metal Bracket V1.0
REV 0
SCALE: 1:3
WEIGHT
SHEET 1 OF 1
REV
DATE Y/M/D
DESCRIPTION
DWN
CKD

QTY: 2





DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE

CHAMFERS
FILLETS
BREAK SHARP
SHARP

THREADED FEATURES EXTERNAL THREADS AT ∅MAJOR INTERNAL THREADS AT ∅MINOR

EDUCATIONAL AND PROPRIETARY
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MATERIAL
PLASTIC

FINISH INDICATE PLATING/COATING/ETC.

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

MECH 4860 - TEAM 18

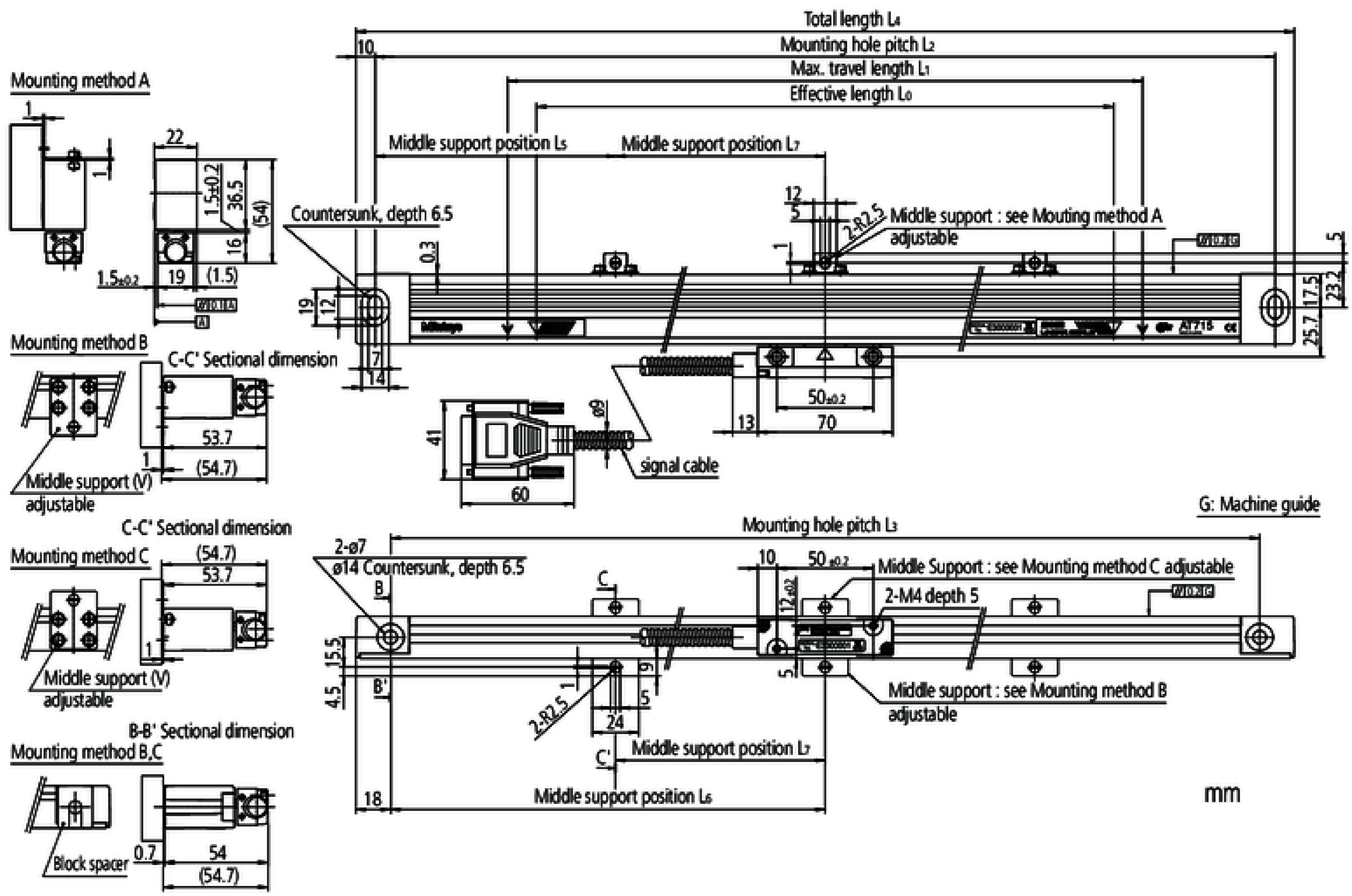
TITLE:
SUPPORT BLOCK

SIZE	DWG. NO.	REV
B	SUPPORT BLOCK	0

SCALE: 2:1	WEIGHT:	SHEET 1 OF 1

REV	DATE Y/M/D	DESCRIPTION	
			DWN NAME # / CKD NAME #
			DWN NAME # / CKD NAME #
			DWN NAME # / CKD NAME #
			DWN NAME # / CKD NAME #
			DWN NAME # / CKD NAME #

DWG. NO.	REV
SUPPORT BLOCK	0



Total length L4
Mounting hole pitch L2
Max. travel length L1
Effective length L0
Middle support position L5
Middle support position L7
Countersunk, depth 6.5
Middle support : see Mouting method A
adjustable
signal cable
Mounting method A
Mounting method B
C-C' Sectional dimension
Middle support (V)
adjustable
Mounting method C
C-C' Sectional dimension
Middle support (V)
adjustable
B-B' Sectional dimension
Mounting method B,C
Block spacer
G: Machine guide
Mounting hole pitch L3
2-ø7
ø14 Countersunk, depth 6.5
Middle Support : see Mounting method C adjustable
2-M4 depth 5
Middle support : see Mounting method B
adjustable
Middle support position L7
Middle support position L6
mm