



School of Engineering MSc Mechanical Engineering

Engineering– M7X01382
Assignment – Design for Manufacture – Drill Press

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Abstract

The assignment considers the improvement of a concept design of a drill press unit through the utilisation of Design for 'X' methodologies. The analysis allows an improved CAD model to be developed for consideration, the component parts are provided in electronic format for consideration alongside this written text. The proposed improvements to the concept design allow saving in the raw material cost and assembly time, and reliability in service.

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1.0 Introduction

The assignment considers a concept model design of a drill press unit which is evaluated using the *Design for X* methodology with the intention of improving the original concept design. The following factors of design for X being considered

- Design for manufacturability
- Design for assembly
- Design for reliability

The findings of the design for X methodologies drive the improvements made to the concept design. The concept design parts and assembly are manipulated within Solidworks 2019, improved parts being saved with sequential part numbers, and assembled as a revised assembly. The Solidworks part and assembly files are submitted for consideration with this assignment. The developed concept design is evaluated against the same design for X criteria as the concept design.

2.0 Existing Concept Design

The existing drill press unit concept design presented for evaluation and improvement development is described in figure 1. The drill press consists of 8 main component parts, which are included within the associated Solidworks drawing parts files.

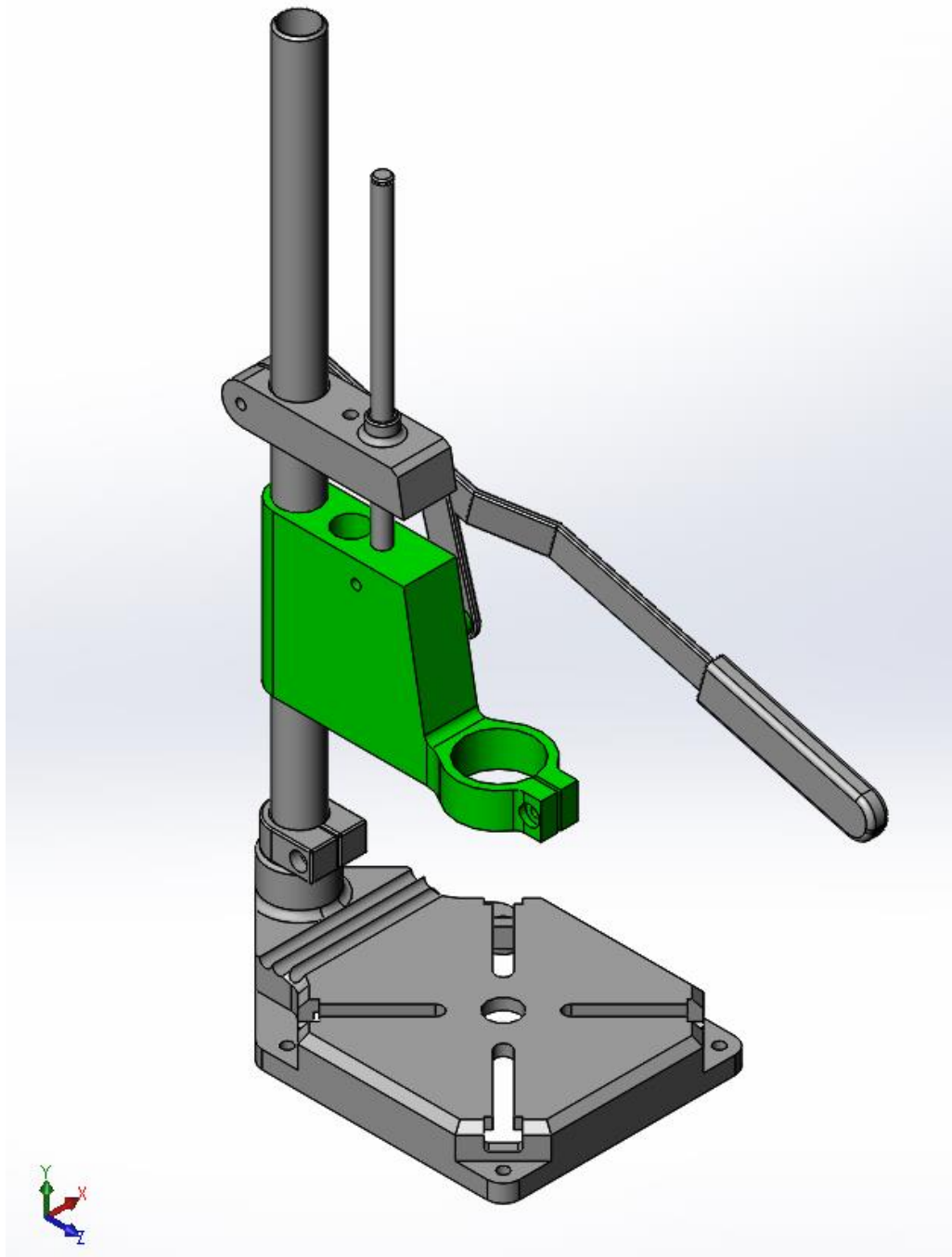


Figure 1. Drill Press Unit – Existing Concept Design

The main component parts which make up the completed assembly being described as follows

1. Base
2. Guide Shaft
3. Lever Arm
4. Link Arm
5. Main Shaft
6. Main Sliding Unit
7. Supporting Clamp
8. Top Brace Clamp

Screw fasteners are omitted from the concept design assembly; however, it is understood that each of the main components will utilise screw fasteners to facilitate positional locking, the fastener positions being indicated by location holes on the main components.

3.0 Evaluation of concept Design – Design for ‘X’

The development of the concept design in this exercise focuses on the *Main Sliding Unit* and *Top Brace Clamp* as both parts are critical to the correct operation of the drill press, and is considered as a sub-assembly. The development of the design is considered through the utilisation of *Design for Manufacture*, *Design for Assembly* and *Design for Reliability* techniques.

A tension spring connects the Main sliding Unit and Top Brace Clamp which provides a closing action to return the drill press to the upper start position, with the guide shaft maintaining alignment during movement. A cross sectional view of the assembly is shown in figure 2, the guide shaft being retained in the sliding unit by a screw fastener, the tension spring being retained by the location bar features to the sliding unit and brace clamp.

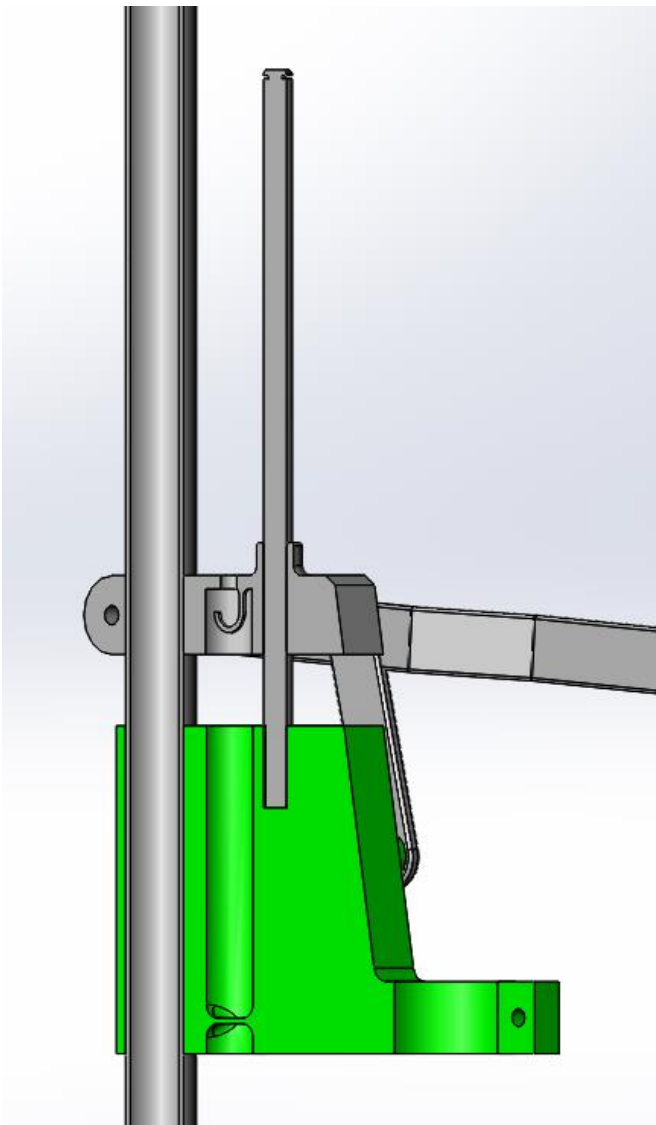


Figure 2. Cross Section View – Existing Concept Design

A prototype model of the drill press was made available as part of the development exercise, the images in figure 3 clearly show the relationship of the tension spring between the sliding unit and brace clamp, the guide shaft and retaining fastener are also visible. A depth gauge is also present on the prototype model which allows the downward movement of the sliding unit to be established. Whilst the depth gauge has not been included on the existing concept design, it is considered to provide an important function in the operation of the drill press and is therefore considered in the development exercise.

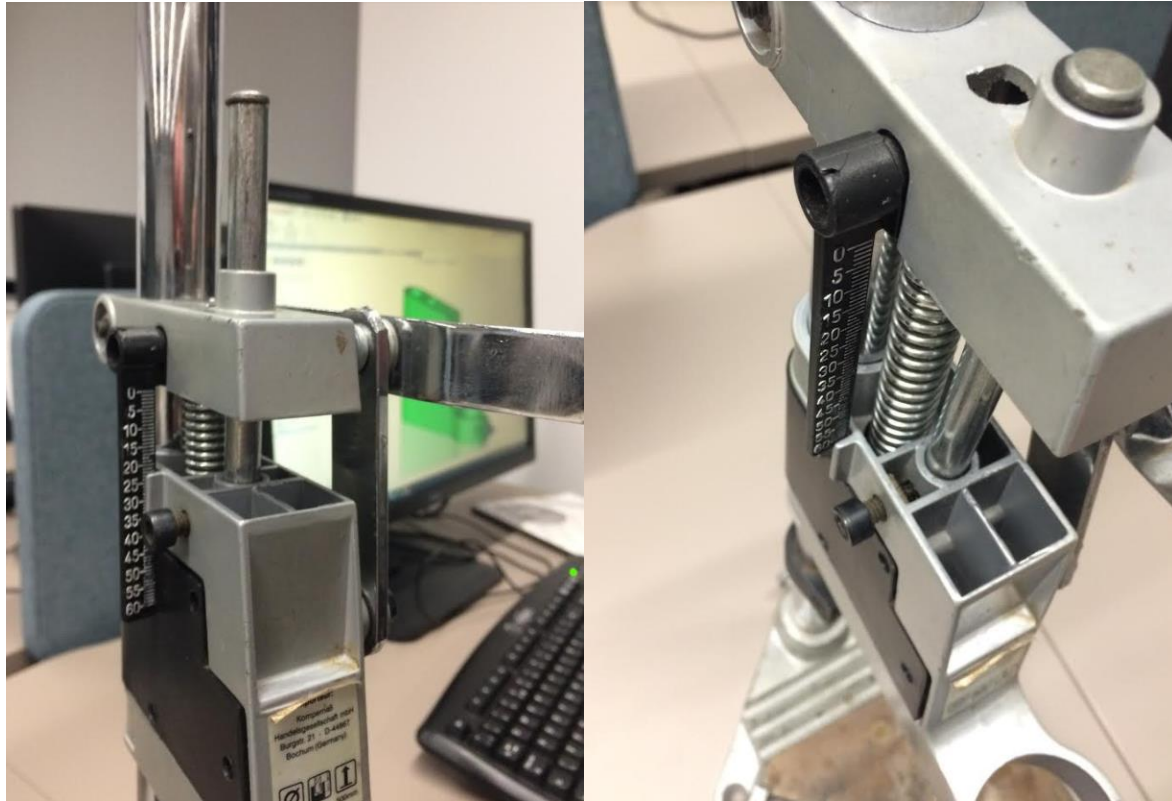


Figure 3. Existing Concept Design – Prototype Model – Tension Spring and Depth Gauge detail

Pugh (1991), describes Design for Manufacture as having two key components, *Design for Assembly* and *Design for piece-part Producibility*. The two parts being directly linked, designing for manufacture and cost; and suggested that the most popular method for achieving efficient design for assembly is by applying the methods set out by Boothroyd and Dewhurst (1994), and also Lucas (Kamrani & Nasr, 2010).

Assessing *Design for Reliability* with a Failure Mode and Effects Analysis (FMEA) through the application of previous design knowledge to a concept design assist in the identification of potential problems, thereby allowing solutions to be incorporated into the concept design during the design stage (Carlson, 2012).

The application of design for manufacture and design for reliability focus on minimising costs associated with development and manufacture of components and those incurred during assembly, and the reliability of the product in use.

3.1 Essential Parts Evaluation

The efficiency of the sub-assembly consisting of the sliding unit, brace clamp, guide shaft and depth gauge is assessed using the Lucas Design Efficiency Method, where essential and non-essential parts are classed as A and B respectively (Table 1). The non-essential parts (B) should be targeted for designing out and include all fasteners.

The design efficiency being expressed as a percentage, and is set out in equation (1)

$$\frac{A}{A+B} \times 100 \% \quad (1)$$

Part	Part Type – A - B
Brace Clamp	A
Sliding Unit	A
Guide Shaft	A
Depth Gauge	B
Guide shaft circlip (fastener)	B
Guide shaft retaining screw (fastener)	B
Brace clamp screw (fastener)	B
Depth gauge screw (fastener)	B

Table 1. Lucas Essential Parts Assessment – Existing Concept Design – Sub-assembly

Applying equation (1), the design efficient of the existing concept design sub-assembly.

$$\frac{3}{3 + 5} \times 100 = 37.5 \%$$

3.2 Assembly Time Evaluation

The assembly time for the sub-assembly consisting of the sliding unit, brace clamp, guide shaft and depth gauge is assessed using the Boothroyd and Dewhurst method. The assembly order of the sub-assembly is assumed as follows

1. Guide shaft placed in sliding unit
2. Retaining screw fitted in sliding unit to lock guide shaft
3. Tension spring fitted to location bar on sliding unit
4. Brace clamp fitted to guide shaft
5. Brace clamp location bar fitted to tension spring
6. Circlip fitted to guide shaft
7. Depth gauge
8. Depth gauge retaining screw

The assembly steps are assessed against the manual assembly evaluation charts for parts that are of a nominal size and weight and are easily handled with one hand. The assembly evaluation chart is detailed in table 2.

			Parts are easy to grasp and manipulate					Parts present handling difficulties (1)				
			Thickness >2 mm			Thickness ≤2 mm		Thickness >2 mm			Thickness ≤2 mm	
			Size >15 mm	6 mm ≤ size >15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm	Size >15 mm	6 mm ≤ size ≤15 mm	Size <6 mm	Size >6 mm	Size ≤6 mm
			0	1	2	3	4	5	6	7	8	9
Parts can be grasped and manipulated by one hand without the aid of grasping tools	$(\alpha+\beta) < 360^\circ$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
	$360^\circ \leq (\alpha+\beta) < 540^\circ$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
		2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
	$540^\circ \leq (\alpha+\beta) < 720^\circ$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4
			Groups 1 & 2 are further sub-divided into categories representing the amount of orientation required, based on the symmetry of the part.									

Key:

One hand

Table 2. Manual Assembly Evaluation Chart (Course notes, 2020)

Assembly Step	α	β	$A + \beta$	Time (s)	Handling code
1	360	360	720	2.25	3-1
2	360	0	360	2.25	1-2
3	180	180	360	2.25	1-5
4	360	360	720	2.25	3-0
5	360	360	720	2.73	3-5
6	180	0	180	2.45	0-8
7	360	0	360	1.8	1-1
8	360	0	360	2.25	1-2

Table 3. Assembly Time – Existing concept Design – Sub-assembly

From table 3, by applying the Boothroyd and Dewhurst method it can be seen that the total time require to assembly the existing concept design sub-assembly is **17.93 seconds**.

3.3 Failure Mode and Effects Analysis (FMEA)

A Failure Mode and Effects Analysis (FMEA) is undertaken on the main sliding unit sub-assembly with focus on the effect of the tension spring failure on operation as described in table 4. The ranking score assigned against Severity, Occurrence and Detection are determined by evaluation criteria described by Carson (2012).

DESIGN FAILURE MODE AND EFFECTS ANALYSIS									
Item:	Sliding Unit (Sub-Assembly)			Responsibility: _____					
Model:	Drill Press Unit			Prepared by: _____					
Core Team:	_____								
Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	RPN	Recommended Action(s)
Sliding Unit Sub-System: Allows downwards movement of mounted drill, integral tension spring returns sliding unit back to start position defined by position of brace clamp	Tension spring does not act on sliding unit and brace clamp	Sliding unit does not return back to start position	7	Number of operating cycles exceeds tension spring fatigue life limit resulting in fracture of spring material	2	None	9	126	None
			7	Sliding unit spring location bar fails due to material thinning over repeated operating cycles.	6	Routine maintenance procedure suggests periodic lubrication of moving parts	5	210	Redesign sliding unit so that a location bar is not required to retain spring
			7	Brace clamp spring location bar fails due to material thinning over repeated operating cycles.	6	Routine maintenance procedure suggests periodic lubrication of moving parts	5	210	Redesign brace clamp unit so that a location bar is not required to retain spring

Table 4. FMEA – Sliding Unit Sub-Assembly – Spring Return

4.0 Development of concept Design – Design for ‘X’

From the essential parts and design efficiency evaluation completed on the existing concept design in section 3.0 several fasteners can be removed by design which will allow a corresponding increase in design efficiency. In turn removing fasteners will also improve the assembly time.

The sliding unit and brace clamp are considered for improvement in manufacture, assembly and reliability. Where the focus is placed on simplifying the design. The FMEA completed identified improved reliability by re-designing the spring return function.

4.1 Main Sliding Unit and Guide Shaft

The sliding unit (figure 4) in addition to the main shaft opening, drill clamp and lever fastening points, contains the tension spring pocket, spring location bar, and guide shaft location and fastening holes.

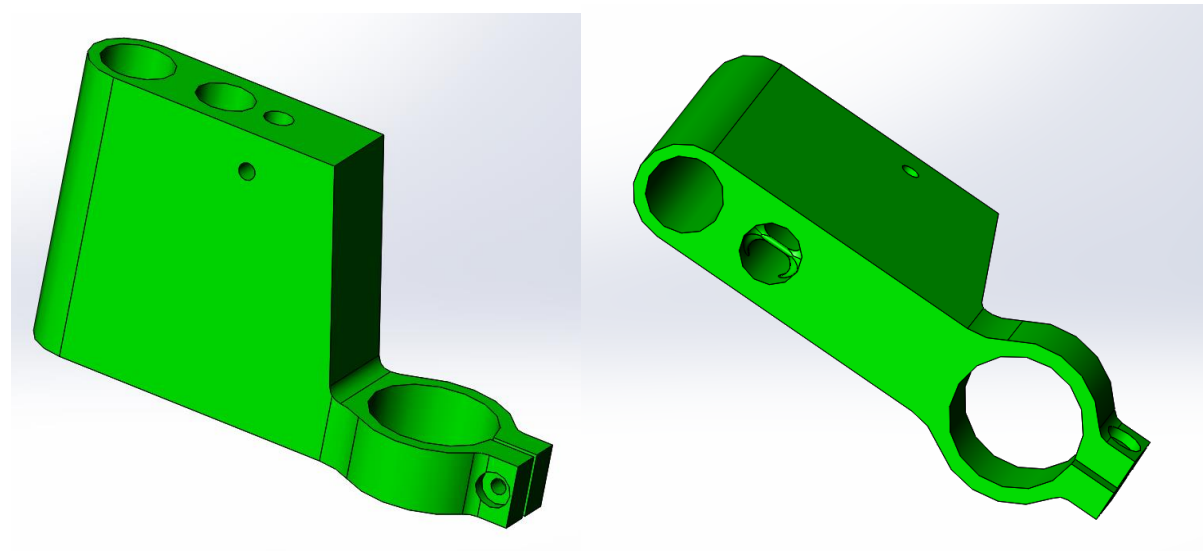


Figure 4. Existing Concept Design – Sliding Unit – Top and bottom views

The spring pocket and spring location bar add complexity to the manufacturing process due to the additional features required within the tooling to form the component. The guide shaft is retained with a fastener and is therefore considered as non-essential. The FMEA identified the spring location bar as an area that is likely to effect reliability.

The model parts are re-designed within Solidworks. The spring pocket and location bar are removed completely (figure 5) from the sliding unit, the tension spring being replaced with a compression spring. The fastener arrangement for the guide location shaft is removed, surplus material is removed from the part. The guide shaft (figure 6) being redesigned to incorporate a forged head to facilitate location and retention (figure 7).

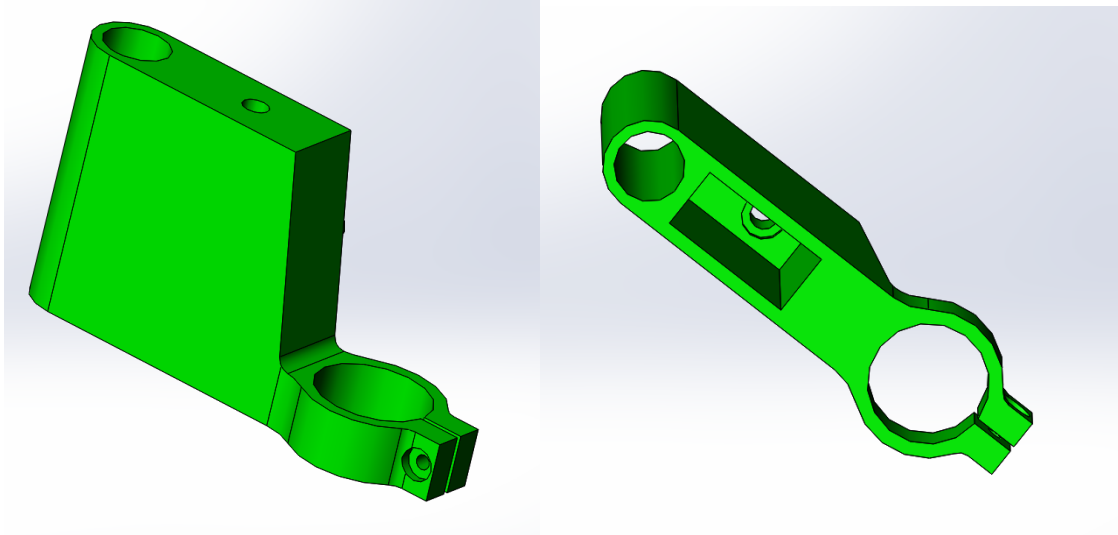


Figure 5. Developed Concept Design – Sliding Unit – Top and bottom views



Figure 6. Existing Concept Design – Guide Shaft



Figure 7. Developed Concept Design – Guide Shaft

4.2 Brace Clamp and Depth Gauge

The brace clamp (figure 8) in addition to the main shaft opening, main shaft clamp and lever fastening points, contains the tension spring pocket, spring location bar, and guide shaft location opening.

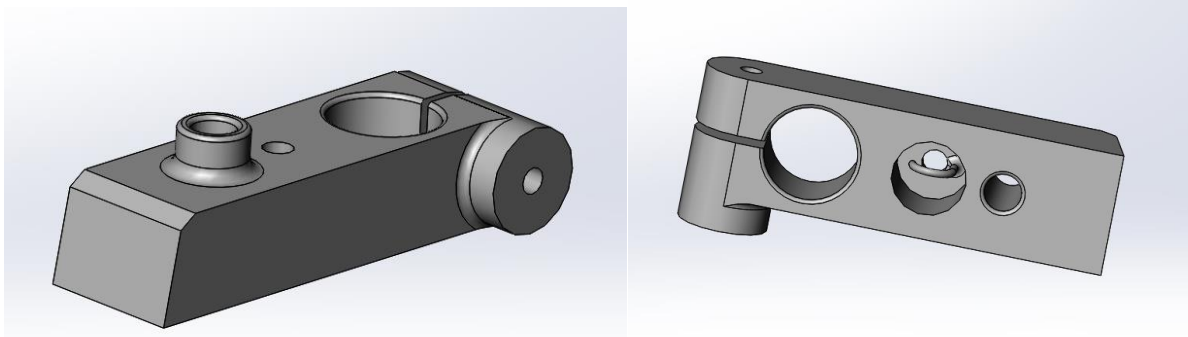


Figure 8. Existing Concept Design – Brace Clamp – Top and bottom views

As with the sliding unit the spring pocket and spring location bar add complexity to the manufacturing process due to the additional features required within the tooling to form the component, the spring location bar posing a potential reliability issue. The depth gauge is not shown on the Solidworks model; however, it is taken that it would take the same form as that of the depth gauge detailed in figure 3.

The model part for the brace clamp is re-designed within Solidworks. The spring pocket and location bar are removed completely (figure 9), the tension spring being replaced with a compression spring. The depth gauge facility is incorporated into the compression spring sleeves which consists of two additional parts situated atop the brace clamp, located on the guide bar, detailed in figure 10. The lower spring sleeve being graduated to facilitate depth measurement.

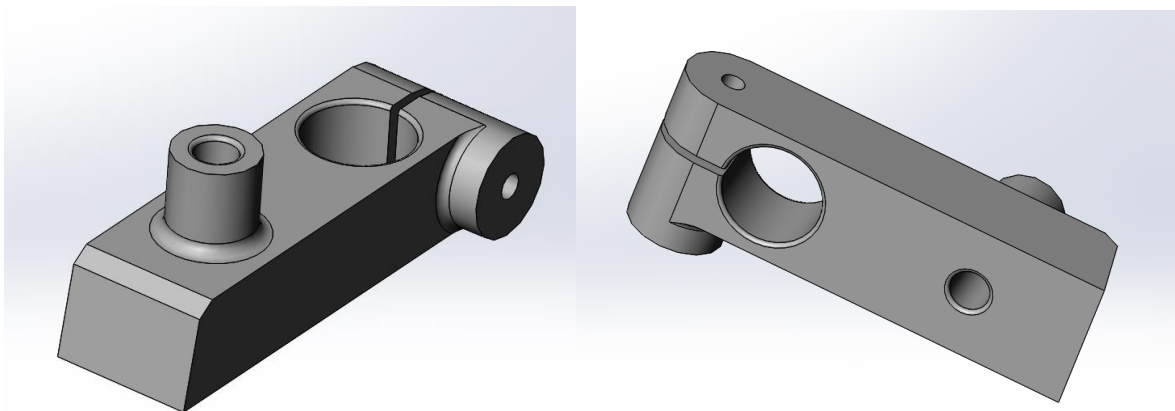


Figure 9. Developed Concept Design - Brace Clamp – Top and bottom views

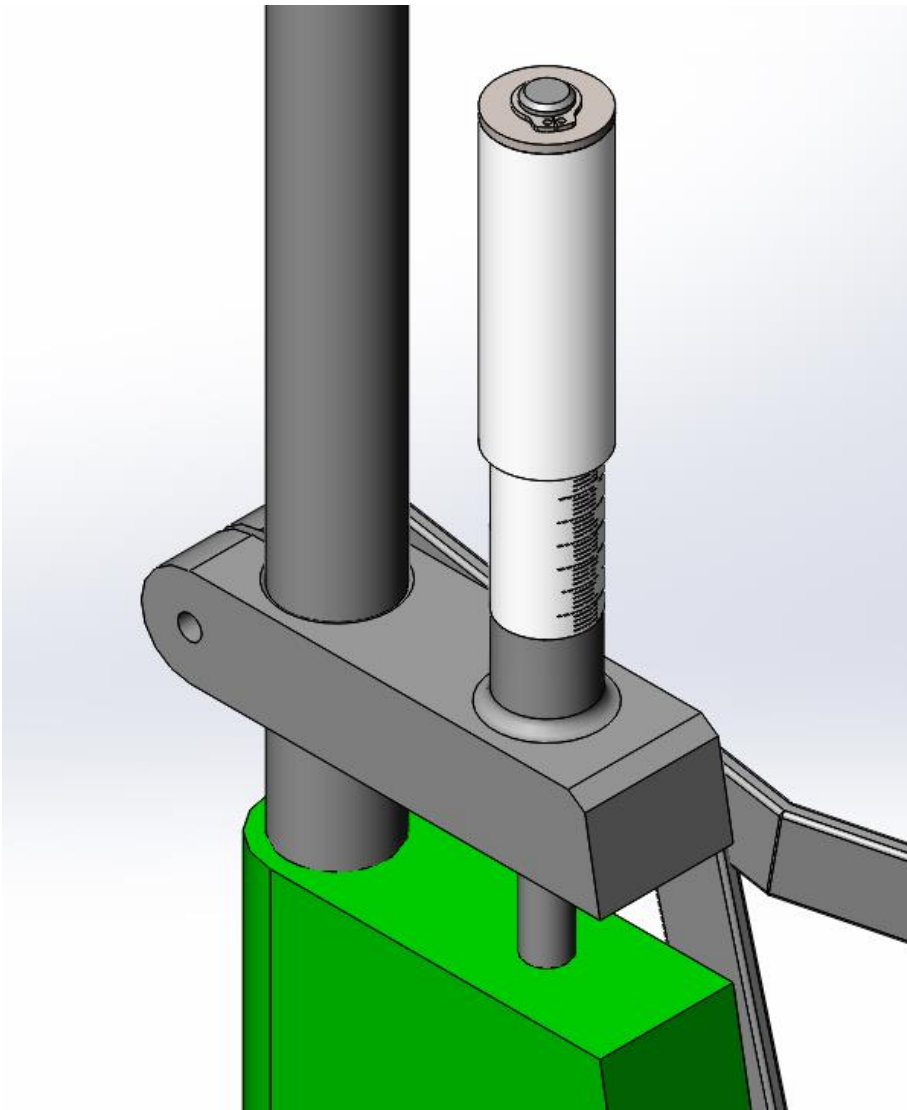


Figure 10. Developed Concept Design – Depth Gauge

5.0 Evaluation of Developed Concept Designs

The developed concept design incorporates significant changes over the existing concept design to allow the removal of non-essential fasteners. The evaluation allowed the tension spring to be replaced with a compression spring, which has advantage in assembly in that the component is fitted from the top, required no location against a spring location bar situated within a pocket. The compression spring force is transferred over a larger area, and not confined to spring location bars which are susceptible to early wear and failure. The principal changes in design is detailed in the sectional images contained in figure 11, (refer to figure 2 for existing concept design section view).

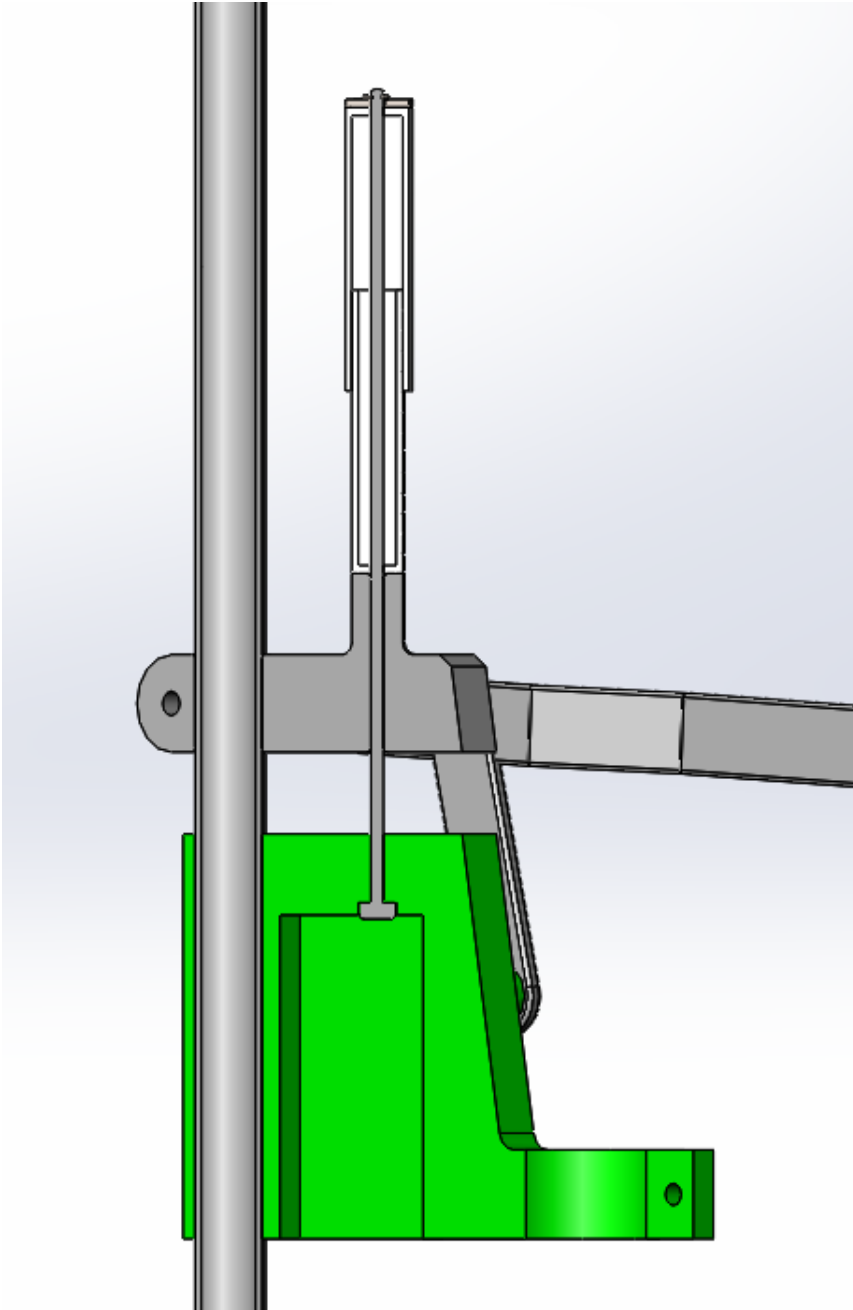


Figure 11. Cross Section View – Developed Concept Design

5.1 Essential Parts Evaluation

The efficiency of the developed concept design sub-assembly consisting of the sliding unit, brace clamp, guide shaft and spring sleeve is assessed using the Lucas Design Efficiency Method, where essential and non-essential parts are classed as A and B respectively (Table 5).

Part	Part Type – A - B
Brace Clamp – Part 202	A
Sliding Unit – Part 201	A
Guide Shaft – Part 103	A
Upper spring sleeve – Part 102	A
Lower spring sleeve – Part 101	A
Upper sleeve washer	B
Guide shaft circlip (fastener)	B
Brace clamp screw (fastener)	B

Table 5. Lucas Essential Parts Assessment – Developed Concept Design – Sub-assembly

Applying equation (1), the design efficient of the developed concept design sub-assembly.

$$\frac{5}{5 + 3} \times 100 = 62.5 \%$$

5.2 Assembly Time Evaluation

The assembly time for the sub-assembly consisting of the sliding unit, brace clamp, guide shaft and spring sleeve is assessed using the Boothroyd and Dewhurst method. The assembly order of the sub-assembly is assumed as follows

1. Guide shaft placed in sliding unit
2. Brace clamp fitted to guide shaft
3. Lower spring sleeve fitted
4. Compression spring inserted into lower spring sleeve
5. Upper spring sleeve fitted
6. Upper sleeve washer fitted to guide shaft
7. Circlip fitted to guide shaft

The assembly steps are assessed against the manual assembly evaluation charts for parts that are of a nominal size and weight and are easily handled with one hand. The assembly evaluation chart is detailed in table 2.

Assembly Step	α	β	$A + \beta$	Time (s)	Handling code
1	360	0	360	1.8	1-1
2	360	0	360	1.8	1-1
3	360	0	360	1.5	1-0
4	180	0	180	1.13	0-0
5	360	0	360	1.5	1-0
6	180	0	180	1.13	0-0
7	180	0	180	2.45	0-8

Table 6. Assembly Time – Developed Concept Design – Sub-assembly

From table 6, by applying the Boothroyd and Dewhurst method it can be seen that the total time require to assembly the existing concept design sub-assembly is **11.31 seconds**.

6.0 Discussion

The utilisation of design for manufacture, assembly and reliability techniques in the evaluation of the drill press concept design specifically with respect to a defined sub-assembly comprising of the main sliding unit, brace clamp, and guide shaft, has shown that the concept design can be improved.

The design efficiency for the sub assembly being increased from 37.5% to 62.5% by the target removal of fasteners which were reduced from 5 to 3.

The assembly time for the sub assembly being decreased from 17.93 seconds to 11.31 seconds.

Significant changes were made to the sliding unit by removing the need for a fastener to retain the guide shaft, which also allowed material to be removed from the part. With consideration to the indicated production rate of 500 units per week where a reduction in material volume of 60.5cm^3 per item is considered a material saving of 1.5m^3 is made over a year at 50 weeks production. This equates in a material cost saving in the region of £6k per annum based on February 2020 material prices at £1.47 per KG for LM24 alloy (Foundry Trade Journal International, 2020).

The development of the sliding unit design also allowed improvements to be made in the position of the return spring arrangements and type of spring utilised. This was considered to add additional time to the part assembly due the tension spring having to located onto spring bars in both the sliding unit and brace clamp. The spring location taking two steps with a total time of 4.98 seconds. By replacing the tension spring with a compression spring, the assembly time for spring location is reduced to 1.13 seconds. The replacement of the tension spring with a compression spring and removal of the spring location bars is likely to substantially improve in service reliability.

The depth gauge was not supplied as part of the existing concept design, however by evaluating the prototype model it was found that the independent side depth gauge could be removed and incorporated into the return spring sleeves. An imported CAD model of a drill (Grabcad, 2019) which would typically be associated with the drill press is shown with the assembly developed concept design in figure 12 and 13, the dimensions being reviewed against manufacturers data (Bosch, 2020).

From figure 12 it is evident that the depth gauge present on the prototype model would not be visible under normal operating conditions on the existing concept design and is unlikely to meet the requirements of the product design specification, by moving the depth guide to the elevated position above the drill on the developed concept design allows the operator to have a clear view during use.

The design has been simplified by the removal of fasteners, this will result in reduced costs associated with manufacturing as the tooling for die casting is simplified by reducing the number of holes and difficult geometric forms (spring bars), also the number of tapping operations are reduced. The milling operation on the guide shaft to produce the location flat is removed, being replaced with a forging process for forming the location head.

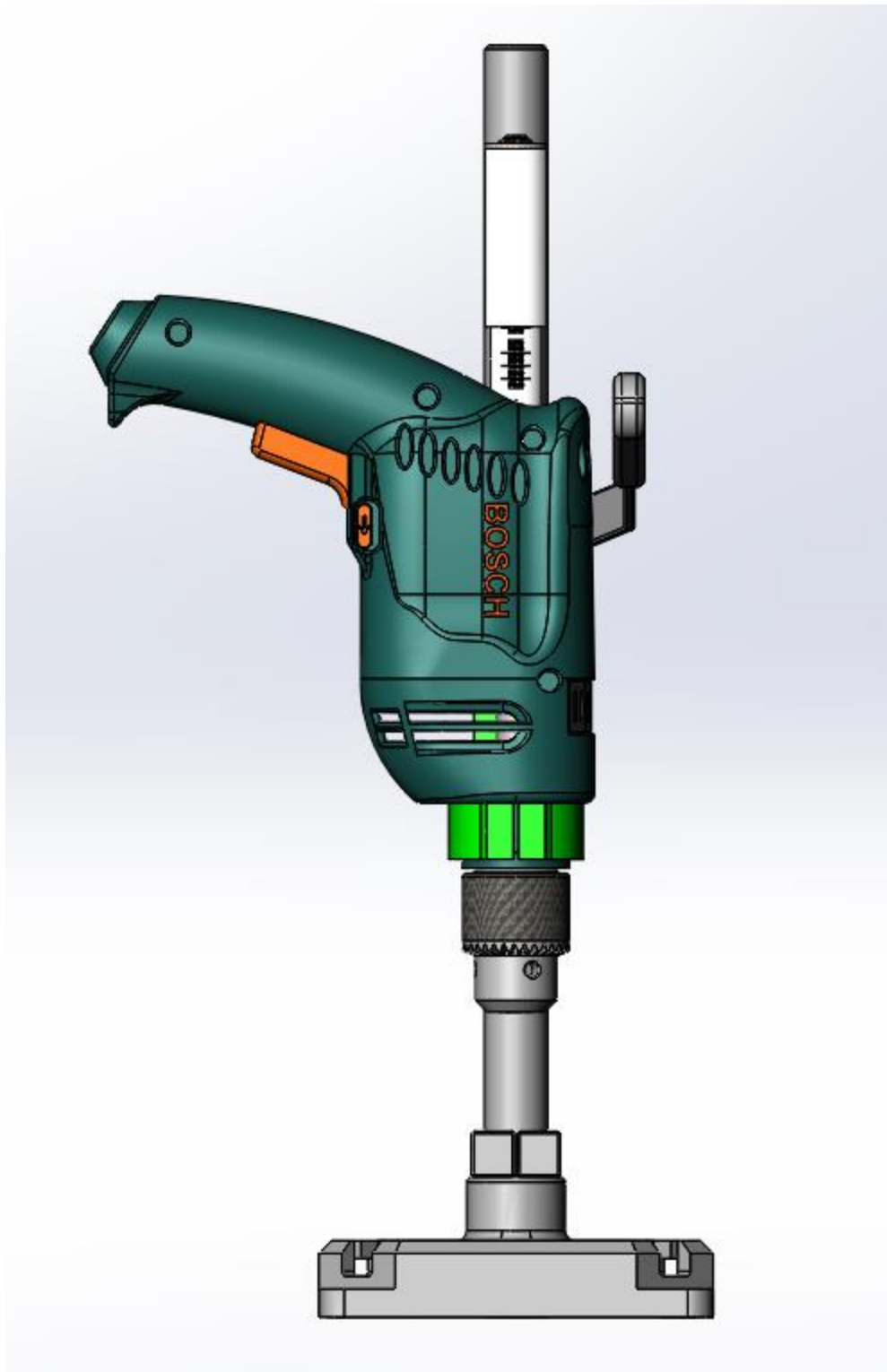


Figure 12. Developed Concept Design – Front View (Simulated with drill)

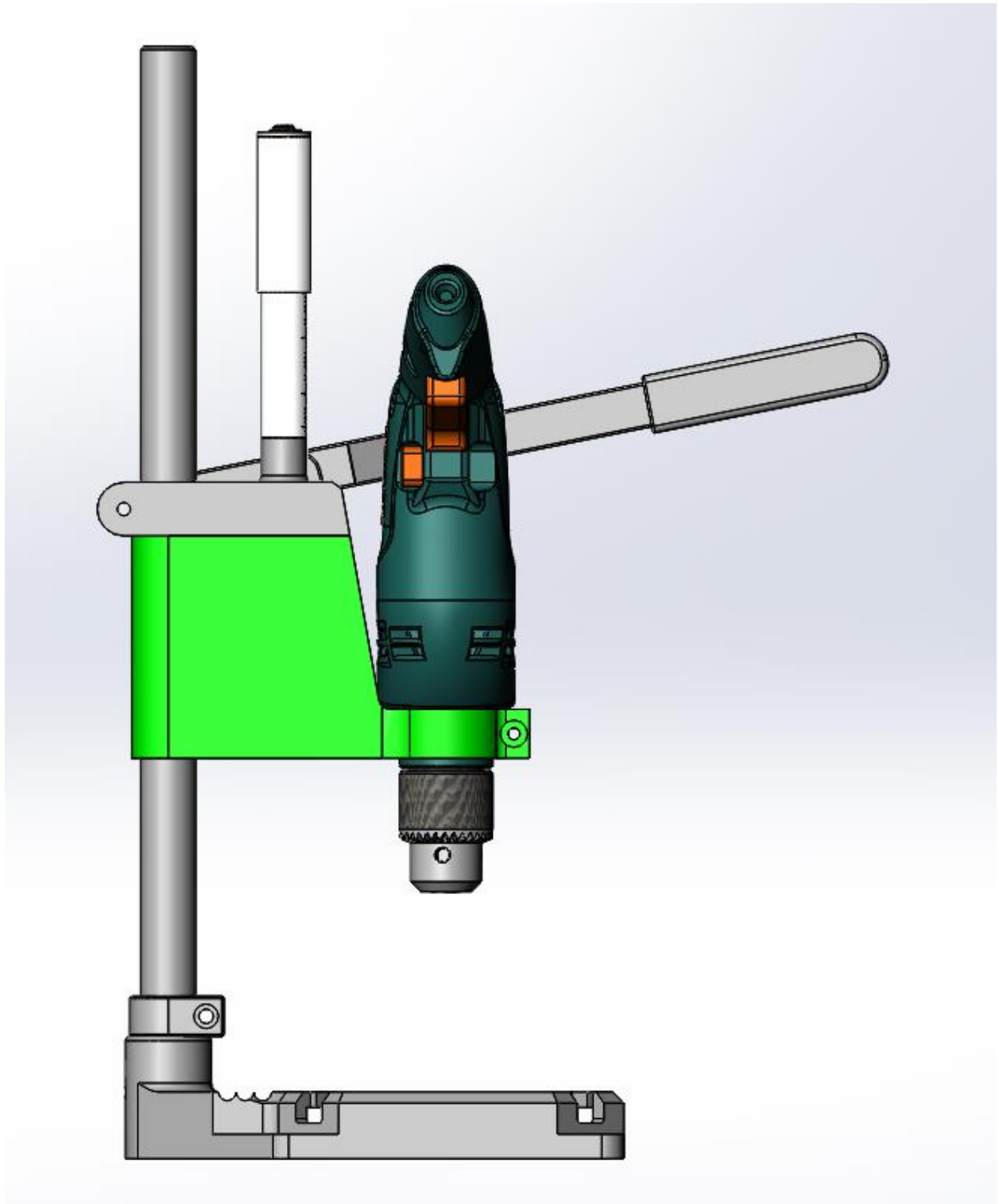


Figure 13. Developed Concept Design – Side View (Simulated with drill)

7.0 Conclusion

The design development exercise has resulted in savings in elements of manufacturing, assembly and raw material costs by utilising the design for manufacture and assembly methods of improvement. Whilst the developed concept design only focused on one sub-assembly of the complete drill press unit, consisting of the main sliding unit, brace clamp and guide shaft. It has been shown that significant savings and improvements can be made by adopting design for 'x' methodologies.

Applying design for reliability and a FMEA study identified that the spring location bars were a weakness in the concept design, through re-design and the specification of a compression spring it is envisaged the design for reliability analysis will increase in-service reliability.

Further development study and design improvement should be considered and applied to the other components of the existing drill press concept design, as other saving and improvements could be realised. The removal of unnecessary material from the sliding unit resulted in a material cost saving, further investigation should include an optimisation study to identify other areas of the full assembly where material saving can be made.

8.0 Digital Solidworks Files

The associated Solidworks files that detail the improved concept design modification to the original components are uploaded in addition to this assignment as electronic copy to Moodle.

The Model file consist of the drill press folder, containing 24 files. A separate folder contains the drill shell model obtained from Grabcad (2020).

The modified parts, assembly and associated drawings listed as

Drill Press Assy Rev0.1

GA Drill Press Assy Rev0.1

Part 101 – Lower Spring Sleeve

Part 102 – Upper Spring Sleeve

Part 103 – Drill Press Guide Shaft

Part 201 – Drill Press Main Sliding Unit

Part 202 – Drill Press Top Brace Clamp

9.0 References

Boothroyd, G., Dewhurst, P. & Knight, W., 1994. *Product Design for Manufacture and Assembly*. 1st ed. New York: Marcel Dekker.

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