Storage System to Improve Material Handling in Mechanical Workshop

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ABSTRACT

This study focuses on improving one of the rack systems used in the Advanced Machining Lab of the School of Mechanical Engineering, UiTM Shah Alam. The main aim is to improve the design of the current rack based on its functionality, reliability, and cost. The initial stage was to understand the current material handling practice and standards in the workshop. Then, new concepts for the storage system were developed and analyzed by using morphology and Pugh charts, considering all the design elements including functionality, safety, accessibility, 5S, as well as First-In, First-Out (FIFO) concepts. Then, the designs were further analyzed and simulated in terms of deformation, load capacity, and failures analysis using finite element analysis (FEA) by using CATIA V5. After that, an optimum design was selected based on its functionality and reliability according to its actual application at the workshop as well as the total fabrication cost to be involved. An optimum design was then selected. The findings also suggest that the improved flow rack system is more likely to minimize the loading and unloading time, and space as well as reduce the number of staff to handle the activities.

Keywords: *Flow Rack; Lean Manufacturing; Material Handling System; Finite Element Analysis*

Introduction

The finest manufacturing practices include not only the use of the most up-to-date machines and technologies but also the system and management. Many manufacturers all over the world employ Lean Manufacturing (LM)

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system, which has proven to be efficient to ensure on-time delivery, maintain quality, improve profit while lowering operating costs, and stay competitive in market needs [1]. The LM system implementation employs a set of Lean tools such as kaizen, 5S, standardized work, Kanban, kitting system, and others, that led to major process improvements [2]. A lean system is built on two pillars: the first is “jidoka”, and the second is “just-in-time” [3]. The main goal of a lean manufacturing system is to produce higher-quality goods at the lowest possible cost and in the shortest period possible by reducing waste [4]. As a result, companies turn to LM when they wish to improve the efficacy and efficiency of their manufacturing operations [5].

A systematic material handling (MH) system, according to several studies, provides several benefits to the production system, including efficient part selection throughout the assembly process [6], improved operator ergonomics [7], reduced walking distance for operators, non-value-added operations, and cycle time [7], lower product cost [8], lower work-in-progress stock, and shorter product lead times [9]. One of the common approaches in the MH system is by using applying a gravity flow rack system (GFR). Generally, GFR is a storage rack with metal layer shelves to load and unload different sizes of components and, it is equipped with rollers or wheels to move components from one point to another by using the force of gravity [10]. In LM, GFR plays an important role to support the effectiveness of one of the LM pillars which is the Just-in-time (JIT) system [11]. JIT requires the delivery of the correct and proper materials in the right quantity, location, time, position, sequence, and cost. This is to ensure that things are produced on schedule and at the highest possible standard of quality [8]. Thus, an efficient yet practical MH system is required to support the JIT system and at the same time help to improve the overall process performance.

The process of handling and distributing materials, on either hand, could be simple or extremely complex depending on the quantity, size, and weight of the items to be delivered. The mode of transportation used, temporary storage systems, material delivery routes, frequency of delivery, and volume per delivery are all important elements in the effectiveness of this system. As a result, the system must be properly created and evaluated before being incorporated into the manufacturing line.

This paper is based on the on-site study which was conducted in the Advanced Machining Lab of the School of Mechanical Engineering, UiTM Shah Alam. The study explores the design and concepts of the GFR system for efficient storage and loading/unloading processes of varieties of workpieces handled in the lab. Computer-aided design of CATIA V5 was also applied to verify and improve the designs and operational rules of material handling systems before physical installation.

Methodology

Gemba: Understanding Existing Practices and Procedures

Observation at the study area showed that the existing material storage system used as shown in Figure 1, was bulk in size at 6096 x1524 x 1828 mm (LxWxH). Due to that, it requires more space to be permanently placed in the workshop. This rack was used to store different sizes and types of workpieces either in solid blocks or cylinders or in long metal sheets. These workpieces will be used by lecturers or students to conduct their research or project in the workshop. During the observation, it was found that the rack was congested with various types and sizes of workpieces. There were some workpieces disorderly placed on the ground as the rack was over capacity to store all the workpieces at one time. This condition caused the area looks disorganized and even dangerous to other users, particularly during loading and unloading activities. There was also no First-in, First-out (FIFO) system to control the stocks and the workpieces were loading without proper labeling onto the rack or the workpieces. Thus, there is a high tendency for the wrong workpiece to be used by students or lecturers.

Figure 1: Existing storage system

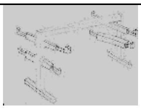
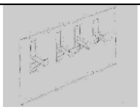
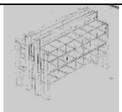
Conceptual design development

The development of conceptual design is an important activity in the design process. This activity must be conducted carefully to avoid any malfunction or incorrect design that may lead to expansive rework and problems after fabrication. In this study, 3 options have been considered for the development of a new metal bar storage rack. Each option comes with different types of materials, criteria, and processes. Table 1 shows the morphological chart for the metal bar storage rack, while Table 2 shows the Pugh chart.

Table 1: Morphological chart – metal bar storage rack

Sub Function	Concepts		
	Option 1	Option 2	Option 3
Frame material	Mild steel	Galvanized steel	Stainless steel
Joint	Welding	Bolts and nuts	-
Basket material	Stainless steel	Mild steel	Stainless steel
Roller bearing	Single bearing	Tapered single bearing	Double bearing

Table 2: Pugh chart - metal bar storage rack

Description		Standard rack	Option 1	Option 2	Option 3
Sketch					
Criteria	Weight	Datum	Option 1	Option 2	Option 3
Durability	1	0	-	0	0
Mobility	2	0	0	-	+
Safety	1	0	0	0	+
Ergonomic	1	0	+	+	+
Easy to use	3	0	0	0	+
Affordable	2	0	+	-	0
+		0	4	1	7
0		10	6	5	3
-		0	1	2	0
Net score		0	3	-1	7

As shown in Table 1, for the frame, mild steel was chosen as it is durable yet the cheapest. For the joining, the welding process was considered as the welded areas generally require less maintenance as compared to the bolts and nuts approach which tends to loosen over time. For a portable concept of a rack, the double roller bearing will be used instead of a single or tapered single bearing. The double bearing can bear more loads axially and radially. Thus more easy to move and control the rack as well as more rigidity.

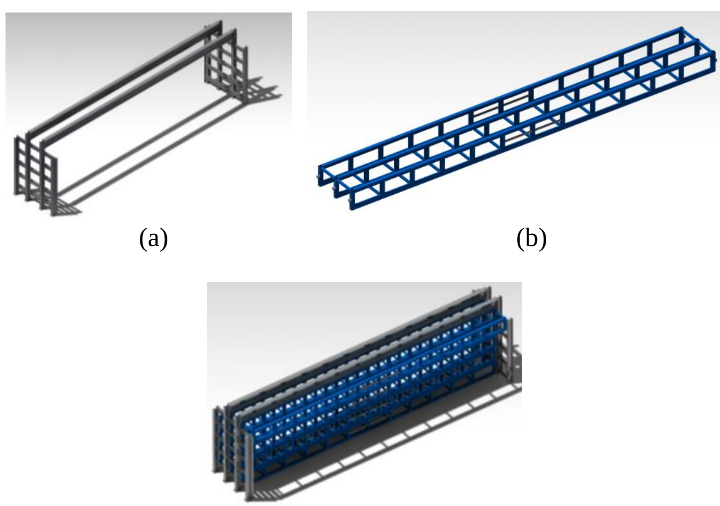
The Pugh chart in Table 2 shows the details of conceptual sketches for option 1, option 2, and option 3 of the metal bar storage rack. Six criteria have been considered which are durable, mobility, safety, ergonomic, easy to use, and affordable. Option 3 has the highest net score, followed by option 1. Therefore, option 3 was selected in this study with its design specifications as shown in Table 3.

Table 3: Matrix of design specification for metal bar storage rack

Requirement design specifications	Details	Unit
Frame material	Mild steel	-
Basket material	Mild steel	-
Type of joint	Welding	-
Ergonomic zone	730 – 1435	mm
Maximum load capacity	2000/basket	kg
Footprint	5.7912	m

3D modeling

A 3D modeling of option 3 was developed by using CATIA V5 as shown in Figure 2. The design consists of 3 main components which are the frame, basket, and roller. For the frame, its material is mild steel at the size of 6221 x 1264 x 1839 mm (LxWxH) as shown in Figure 2a. The frame structure consists of 3 parts which are ‘I’ shaped steel, ‘L’ shaped steel, and a 2 mm thick steel plate. While for the basket as shown in Figure 2b, is also mild steel at the size of 5891 x 759 x 305 mm (LxWxH). The other components are hollow steel square, hollow steel square, hollow steel tube, and steel tube. In Figure 2c, the assembled 3D model of the rack is shown where it has 5 rows of the basket to load different types and sizes of workpieces.



(a) (b)

(c)

Figure 2: CAD model of the metal bar storage rack; (a) frame, (b) basket, and (c) assembled product

Finite Element Analysis

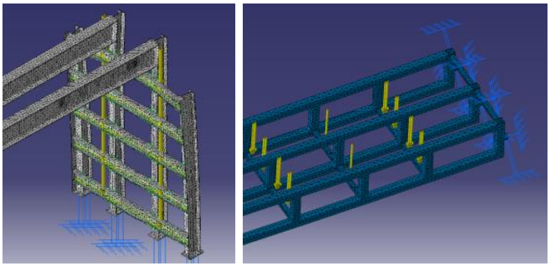
CATIA V5 was applied to conduct Finite Element Analysis (FEA) on the rack system. Welded joints were used to presume a relationship between the components. By merging the components into a single design, the welded joints were defined in CATIA V5. It was done by presuming there would be no connection failures during the analysis. This method has the advantages of saving labor time and reducing errors during static analysis.

Mesh is then generated to create a finite element model using elements and nodes. Meshing is a technique for simulating a physical structure using a set of simple geometric objects known as Elements. At points known as Nodes, these elements are then linked to one another [12]. The mathematical idealization of the structure is represented as a mesh. Table 4 shows the number of nodes and elements used in this study. After that, the restraints and loads on the model were established and analyzed. Any static analysis requires a linear static calculation using restrains and loads as references. The displacements are zero in all 3D directions according to the clamp condition, as shown in Figure 3.

Table 4: Nodes and element quantity

Part	Nodes	Element
Frame	256367	124106
Basket	213905	108486

For the metal bar storage rack, the FEA was performed by using a distribution load of 2000 kg for each basket per row. The load of 2000 kg is converted into Newton according to the load unit requirement on CATIA V5, where 1 kg is equal to 9.81 N, to make the total load of 19, 620 N.



(a) (b)

Figure 3: Clamp and mesh conditions for (a) frame, and (b) basket

Design Factor and Safety Factor

Generally, the safety factor, also known as yield stress, is the amount of stress that the model can withstand, while the design factor or also known as working stress, is the amount of stress that the model has to withstand. The factor of safety (FOS) can be measured by using Equation 1.

$$Factor\ of\ safety = \frac{Maximum\ stress}{Working\ or\ Design\ stress} \tag{1}$$

The value of FOS must be greater than 1 for the design to be acceptable and safely function [14].

Material Properties

In this design, most of the components are mild steel. Mild steel is low-carbon steel with 0.05-0.25 %wt carbon, as compared to high carbon steel which has 0.30-2.0 %wt carbon [15]. Thus, mild steel is more ductile, machinable, as well as weldable. However, it tends to oxidize when exposed to the atmosphere as it lacks alloying elements. This material is also comparatively inexpensive when compared to other steels [15]. The metal properties are shown in Table 5.

Table 5: Matrix of material properties

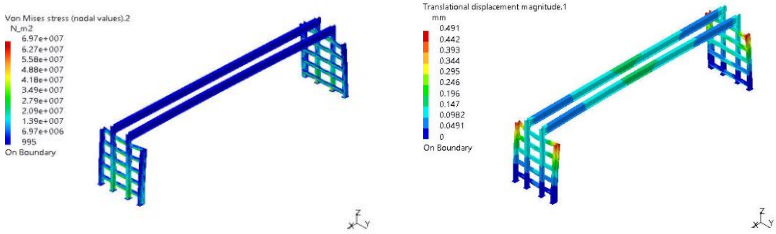
Material	Mild Steel	Galvanized Steel	Stainless Steel	Unit
Density	7850	7850	7500-8000	kg/m³
Ultimate tensile strength	400-550	400	505	MPa
Yield strength	250	300	215	MPa
Young's modulus of elasticity	200	210	193-200	GPa

Result and Discussion

For the frame, its von mises stress and translational displacement are shown in Figure 4. The maximum von mises stress and translational displacement is 6.97 e^7 Pa and 0.491 mm, respectively. Its factor of safety (FOS) is 3.59 as calculated below:

$$Factor\ of\ Safety_{frame} = \frac{250\ MPa}{6.97e^7\ Pa} = 3.59$$

Since its FOS is greater than 1, it means that the structure is suitable to be applied for the intended purposes.



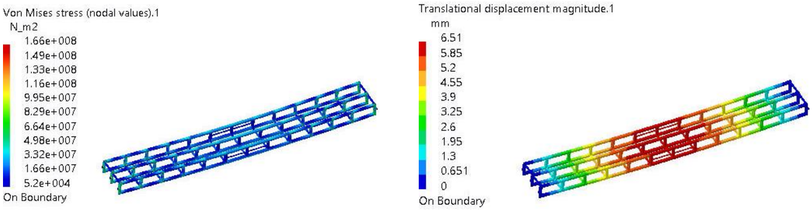
(a) (b)

Figure 4: Frame; (a) Von mises stress, and (b) translational displacement

For the basket, its maximum von mises stress and translational displacement is 1.66 e^8 Pa and 6.51 mm, respectively as shown in Figure 5. The factor of safety for basket storage is 1.51, as calculated below;

$$Factor\ of\ safety_{basket} = \frac{250\ MPa}{1.66e^8\ Pa} = 1.51$$

Since the FOS of the basket is greater than 1, it can be said that any permanent deformation may not happen with a total load of up to 3000 kg. Therefore, the structure of this basket is considerably safe to withstand the maximum load of the design which has been set at 2000 kg.



(a) (b)

Figure 5: Basket, (a) Von mises stress; (b) translational displacement

Table 6 shows the estimated cost of each component that will be used to fabricate the new metal bar storage rack. The total cost that includes the frame, flat bar, roller double bearing, hollow tube, and the rectangular hollow frame is RM7, 316.00. Since the rack is portable, a high-quality bearing is proposed to ensure the rack can be easily moved and at the same time able to withstand the load safely. Therefore, it can be said that the price is reasonable and considered inexpensive when compared to the prices of other ready-made storage racks in the market.

Table 6: Estimation of cost of metal bar storage rack

Material	Quantity	Price (RM)/unit	Total (RM)
Mild steel angle-frame	1	82.77	82.77
Mild steel C-channel-frame	3	134.00	402.00
Mild steel flat bar-frame	3	44.58	133.74
Mild steel flat bar-frame	2	118.65	237.30
Mild steel flat bar-frame	2	154.16	308.32
Mild steel tube hollow-basket	1	89.74	89.74
Mild steel tube hollow-basket	8	200.48	1603.84
SKF roller double bearing	6	743.05	4458.3
		Grand Total (RM)	7316.01

Conclusion

The mains focuses of this study is to design a new metal bar storage rack that is specifically to be used to load and unload different sizes of workpieces in one of the Mechanical Engineering workshop in UiTM Shah Alam. To aid in a better understanding of the design selection procedures, the design aspects were described in terms of the development of the conceptual design. The static analysis has proved that the proposed model structures meet the safety requirements. Therefore, the new proposed metal storage racks system is believed could improve the existing rack in terms of functionality, loading and unloading time, space, safety as well as ergonomics for its intended use.

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