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DESIGN OF ROTARY TABLE OF AUTO TIGHTENING FRONT CUSHION MACHINE AT PT. MATAHARI MEGAH

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ABSTRACT

Rotary table is a mechanism commonly used in production lines in the field of automation. One of the design requirements for the rotary table arises during the design process of the Auto Tightening Front Cushion machine which is manufactured by PT. Matahari Megah. However, there is design challenge faced in designing the rotary table system for bolt tightening process on the motorcycle front cushion as the workpiece that requires a high level of precision. Therefore, this study aims to design a rotary table system that meets both functional and economic. The cost-effective design method employed is function-oriented design and VDI 2221 to obtain the most effective design solution. By applying this method, a rotary table design is obtained with a frame made of aluminium profile and pneumatic cylinder drive system equipped with a locking mechanism. Furthermore, a safety assessment of the rotary table design, considering Von Mises stress, deflection, and safety factor which has minimum safety factor of 3.19 for combination load. It indicates that the design is safe and manufacturable. Subsequently, the FESTO round pneumatic cylinder with the type DSNU-40-250-PPV-A is selected as the driving mechanism for the rotary table system. Thus, the designed rotary table can be integrated into the Auto Tightening Front Cushion machine to perform bolt tightening functions automatically and has good precision.

***Keywords**: Rotary table, automation machine, automatic bolt tightening, safety assessment*

1. Introduction

Rotary table technology as a part of automation machine is developed greatly during the complexity of industrial needs. Automation machine in industrial field must be worked automatically and precisely thus it increase productivity [1]. PT. Matahari Megah is engineering company located in Jl. Raya Serang km 9.5 Kadu Jaya, Tangerang, Banten, Indonesia which fulfills design requirements of automation machine for industrial need [2]. Furthermore, the need for designing machine which satisfies bolt tightening into motorcycle front cushion as the workpiece in 22 seconds and can be loading unloading easily by operator leads the realization of automation machine for helping the operator during production. Cycle time is one of important factor in automation and can be defined as the time needed to process workpiece at the certain station during production process or assembly [3]. As there is need for rotary design from customer for bolt tightening in the workpiece initiates the PT. Matahari Megah to further study in designing rotary table including the integration method into production line.

However, rotary table system design has limitation in area and overall system mass which makes the rotation will be further considered to satisfy the cycle time. Then, in the mechanical rotation system, moment of inertia becomes significant to overall system performance [4]. Based on the problem elaborated, this paper focused on design of rotary table system in the Auto Tightening Front Cushion machine will emphasize analyzed with function-oriented and VDI 2221 such that fulfills industrial need. Michael, *et al* utilized VDI 2221 to design single axis robot and color sorting system that is potential to be implemented in the industry [5]. Loffler, *et al* used VDI 2221 design framework to develop joint assembly with wire actuator made of shape memory alloy [6]. VDI 2221 is appropriate for both design and development phase in industry. The aim of the present study is to design the rotary table system and mechanism in the Auto Tightening Front Cushion machine which satisfies function criteria and economical factor and can be integrated with overall assembly system well.

2. Design Methodology

The design methodology used in the rotary table system in the Auto Tightening Front Cushion machine is a design method with function-oriented design and VDI 2221 to create coherent framework [5]. During the design process, the function is treated as the design baseline to obtain the best and the most effective solution. This concept is agreed with Lee and Suh in their book which discusses about implementation of function-oriented design method and axiomatic design especially in designing efficient and reliable composite structure [7]. Then, VDI 2221 specifies function and sub-function into design concept variants that the most suitable for design phase. Furthermore, the flowchart of rotary table design can be provided in Figure 1.

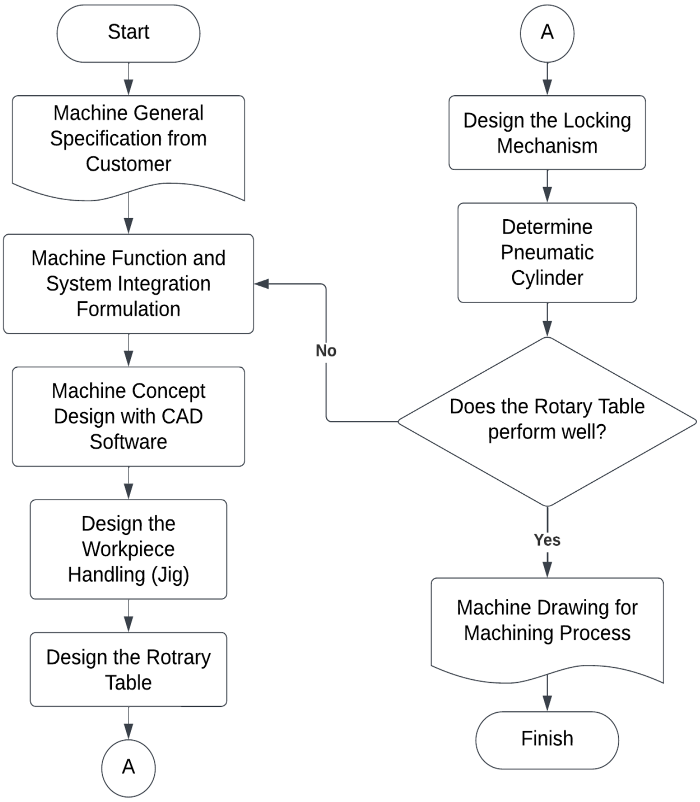


Figure 1. Flowchart of rotary table design in Auto Tightening Front Cushion machine design

3. Result and Discussion

This section will elaborate design selection process, strength checking, and determination of pneumatic cylinder size needed for rotating the rotary table system.

3.1. Rotary table design selection

Rotary table design must consider some design criteria as tabulated in Table 1. The workpiece and bolts that will be tightened as the main machine function can be depicted in Figure 2.

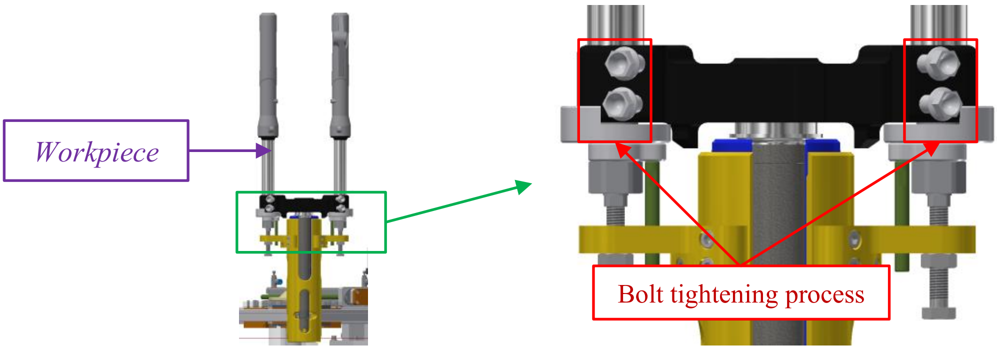


Figure 2. Workpiece in the Auto Tightening Front Cushion

Table 1. Rotary table design criteria

No.	Aspect	Description
1	Workpiece handling	• The number of workpieces in the system is 3. • Cylindrical jig design consideration to support exactly at workpiece center of gravity.
2	Rotary table design	• Frame consideration to ensure robust system design. • Economical factor consideration for rotary table system.
3	Drive mechanism	• Drive method consideration that satisfies economical factor. • The angular speed is suitable with design requirement.
4	Locking mechanism	• Locking mechanism consideration to achieve high precision since the system will perform assembly process.

Then, the function block diagram and the sub-function block diagram of rotary table design can be provided in Figure 3 and Figure 4. The main function of Rotary Table of Auto Tightening Front Cushion machine can be described as follows: (1) operator loading the Workpiece into the first station and doing assembly Steering Stem; (2) tightening 3 x 2 synchronous Front Cushion Bolt with torque target 59 - 68 Nm with Servo Nut Runner; (3) manual tightening the front fender of Workpiece and manual unloading from the station by another operator. Rotary table design concept can be grouped into Table 2. Based on the design concepts, there are 3 concept variations that have opportunities to be realized. Nevertheless, there are some considerations to be discussed regarding rotary table design criteria.

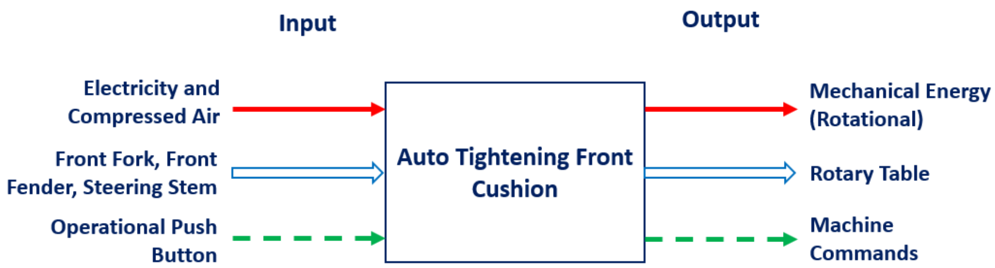


Figure 3. Function block diagram

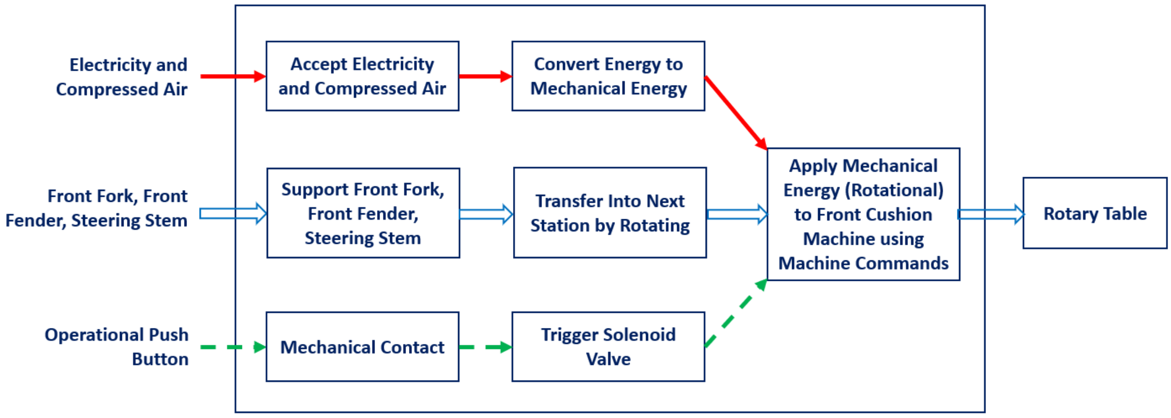
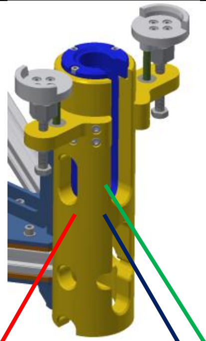
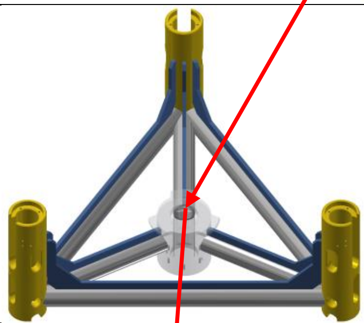
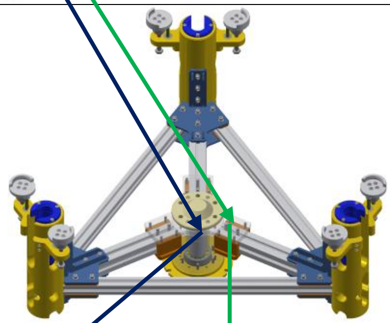
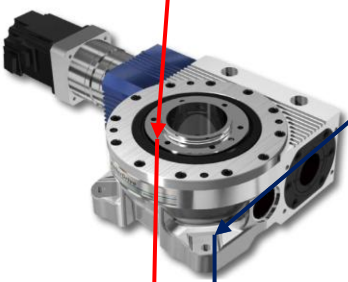
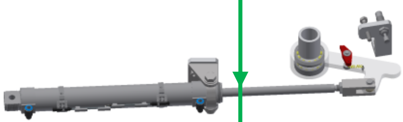
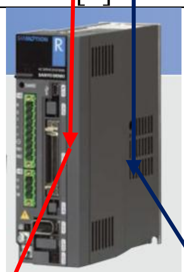
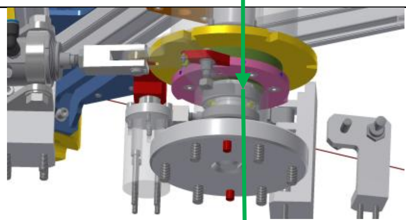


Figure 4. Sub-function block diagram

Based on Table 2, all concept variations utilize cylindrical jig model as workpiece handling which can support the workpiece exactly in its center of gravity. Concept I (red line) uses rotary table frame made by mild steel pipe that has 47 kg mass. This system mass is not optimal to the rotary table rotating mechanism. Then, special welding methods must be implemented to manufacture the frame since the rotary table construction needs to be precise enough that makes it not economical. Therefore, rotary table frame design made by mild steel pipe is less effective for design requirements which must satisfies rotating mechanism and economical factor.

Furthermore, Concept II (blue line) utilizes rotary table frame made by aluminum profile which has less overall system mass, that is 43 kg. It gives optimization to rotating mechanism for better maneuver and carries ease manufacture that reduces overall production cost. Therefore, rotary table frame made by aluminum profile is chosen as final design. However, the use of electrical motor with servo motor type as rotary table drive which needs high precision having potential to increase the production cost for simple function. Since the servo motor is not suitable with design requirement, it must be replaced with alternative rotary drive.

Table 2. Rotary table design concept variant

No.	Aspect	Concept	
1	Workpiece handling		
2	Rotary table frame design		
3	Drive mechanism	 [8]	
4	Locking mechanism	 [9]	
		I II	III

Then, Concept III (green line) is adjusted from previous concept especially the drive mechanism which uses pneumatic cylinder according to the optimal design need. Although more optimal, the use of pneumatic cylinder needs an additional locking mechanism consisting of ratchet mechanism and pneumatic cylinder stopper to start and stop rotation. An additional mechanism can be accepted to ensure the rotary table has good precision. Therefore, rotary

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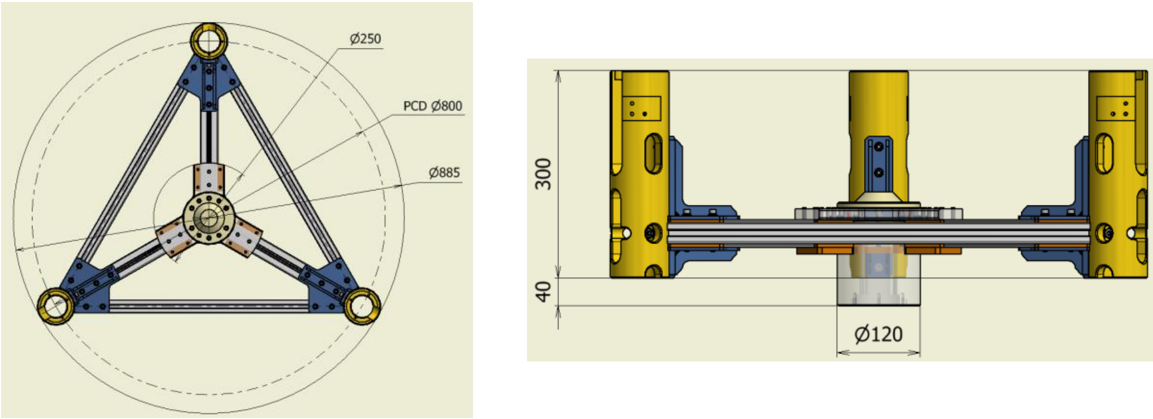
table design in Concept III is chosen and will be implemented in Auto Tightening Front Cushion machine. Furthermore, rotary table general dimension and rotating mechanism can be depicted in Figure 5 and Figure 6, respectively.



(a) (b)

Figure 5. General dimension of selected rotary table of Auto Tightening Front Cushion machine: (a) top view and (b) side view

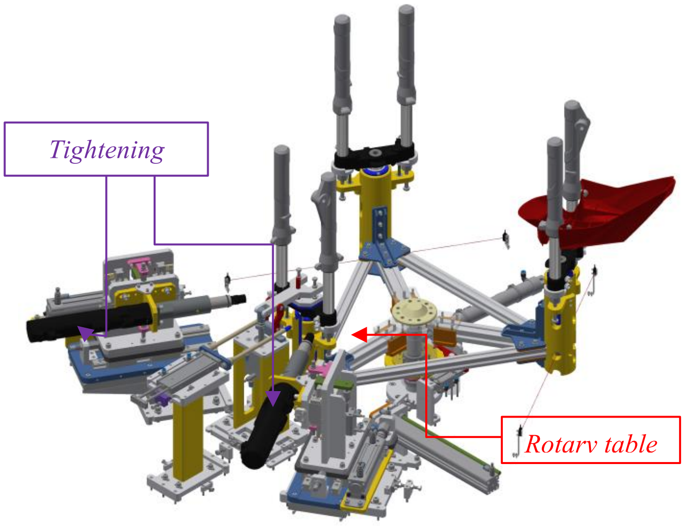
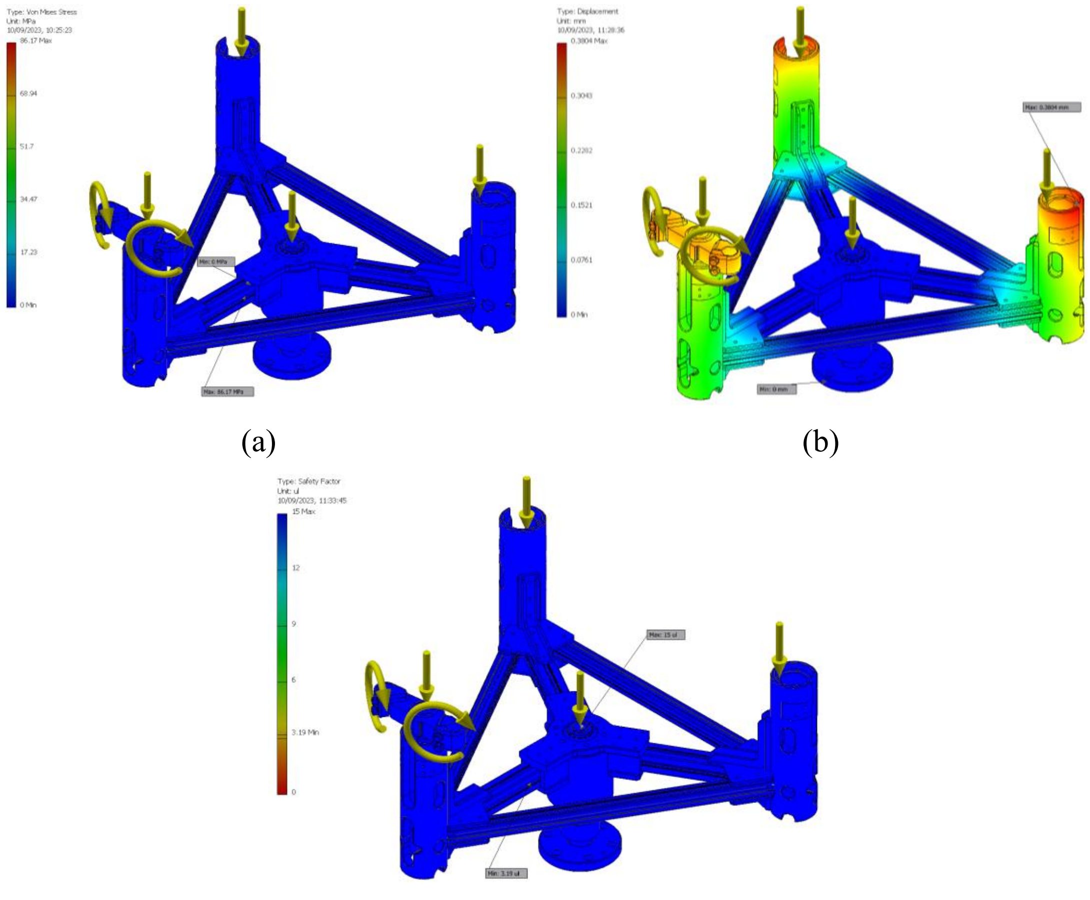


Figure 6. Rotary table of Auto Tightening Front Cushion machine

3.2. Rotary table strength checking

Rotary table design strength checking in Auto Tightening Front Cushion can be analyzed from: Von Mises stress, deflection, and safety factor [10]. The internal stress and deflection can be evaluated in detail using finite element analysis [11]. Then, finite element analysis using Autodesk Inventor software is conducted to evaluate rotary table design strength which can be depicted in Figure 7.

Based on Figure 7(a), the highest Von Mises stress in the rotary table frame is 86.17 MPa. However, this value is safe since the yield strength of Aluminum 6061-T6 is 297 MPa [12]. Furthermore, the highest deflection in the jig area that supports workpiece is 0.38 mm and can be seen in Figure 7(b). This deflection is still safe since the highest deflection allowed for design requirement is 0.5 mm. Safety criteria of overall rotary table design can be evaluated from minimum safety factor of the system when running in combination load, that is 3.19 as provided in Figure 7(c). This safety factor is safe when the low impact condition on the combination load only needs 2 safety factor [13]. Based on these evaluation results using finite element analysis, the rotary table design of Auto Tightening Front Cushion machine can be concluded safe and can be manufactured.



(a) (b)

(c)

Figure 7. Finite element analysis *at the* rotary table *for combination load*: (a) Von Mises stress; (b) *deflection*; dan (c) safety factor

3.3. Determination of rotary table mechanism

Rotary table of Auto Tightening Front Cushion machine is driven by pneumatic cylinder. Determination of pneumatic cylinder size needed can be provided as follows:

3.3.1. Identification of free body diagram system. The rotary table mechanism of Auto Tightening Front Cushion machine can be depicted in Figure 8. Furthermore, simplification of the mechanism can be modelled into free body diagram as seen in Figure 9. Support arm mass in the free body diagram will be calculated as effective mass with the main arm mass and is simplified into green coloured bar. Furthermore, workpiece mass supported by the jig will be treated as concentrated mass (it will be marked with blue circle in Figure 9(b)) thus jig shape factor will be calculated in moment of inertia calculation of shape factor.

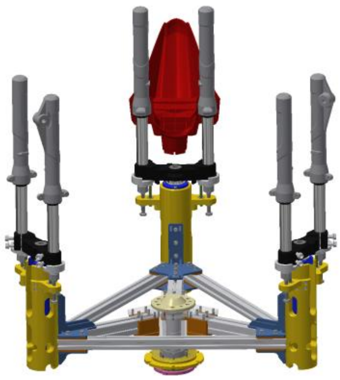
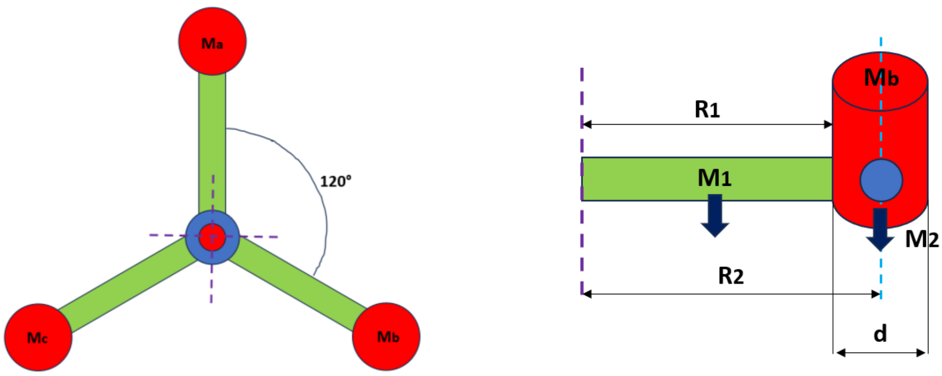


Figure 8. Rotary table mechanism *of* Auto Tightening Front Cushion machine



(a) (b)

Figure 9. Free body diagram of rotary table of Auto Tightening Front Cushion machine for one arm: (a) top view; dan (b) side view

3.3.2. Calculation of required torque. The required torque for rotating the rotary table of Auto Tightening Front Cushion machine becomes the baseline for determining pneumatic cylinder size. Torque calculation is conducted by considering the relation between system moment of inertia and angular acceleration as provided in Eq. (1).

$$\tau_{system} = (SF)I\alpha \quad (1)$$

Where:

τ_{system}	:	Torque required for rotating the rotary table (Nm)
SF	:	Service factor of system operation
I	:	Momen of inertia of total system (kg m^2)
α	:	Angular acceleration of system (rad/s^2)

Furthermore, based on free body diagram in Figure 9 and equation of torque calculation, then data needed for calculating pneumatic cylinder can be provided in Table 3. The data in Table 3 is provided for single arm only since the rotary table system of Auto Tightening Front Cushion machine has symmetrical form, thus it can be analyzed by considering single arm only and the total value will be times by 3 (as total arm in the system is 3).

Table 3. Data *of* rotary table system *of* Auto Tightening Front Cushion machine *for single arm*

No.	Variable	Notation	Value
1	Affective arm mass	M_1	5.5 kg
2	Radius of effective arm	R_1	0.4 m
3	Radius of cylindrical shape factor	d	0.085 m
4	Effective mass of workpiece and jig workpiece	M_2	15 kg
5	Distance between center of rotation to center of cylinder	R_2	0.442 m
6	Service factor	SF	1.5
7	Length of arm mechanism that rotates the rotary table	r_{torque}	0.135 m

Inertia calculation for every arm can be conducted by considering the effective arm construction and effective mass of workpiece and jig workpiece as provided in Eq. (2) [14]. Then, the value of ${k_2}^2$ can be obtained by assumption of the jig shape factor similar to cylinder, thus can be analyzed using Eq. (3) [14]. Based on equation of moment of inertia in Eq. (2), the moment of inertia for single arm can be obtained in the amount of 3.237 kg m^2.

$$I = \frac{M_1 {R_1}^2}{3} + M_2\left({R_2}^2 + {k_2}^2\right) \tag{2}$$

$${k_2}^2 = \frac{d^2}{8} \tag{3}$$

Based on Eq. (1) and Table 3, also angular acceleration of rotary table system in the amount of 1.05 rad/s^2, accordingly the torque value for single arm can be obtained in the amount of 5.098 Nm and the total torque for overall system (all arm) is 15.294 Nm. Therefore, the size of pneumatic cylinder that rotates the rotary table can be analyzed by considering critical angle, θ of 23° as seen in Figure 10 and Eq. (4), thus force of pneumatic cylinder needed to rotate the rotary table is 289.941 N. Based on the cylinder specification, FESTO round cylinder pneumatic DSNU-40-250-PPV-A (as depicted in Figure 11) is chosen as driven element for rotary table.

$$\tau_{required} = F_{sp} r_{torque} \, sin \, sin \, \theta \tag{4}$$

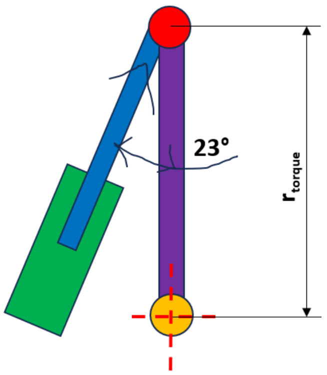


Figure 10. Free body diagram of pneumatic cylinder mechanism that rotates the rotary table

Figure 11. FESTO *round cylinder pneumatic* DSNU-40-250-PPV-A type [15]

Furthermore, implementation of FESTO round cylinder pneumatic chosen in the ratchet mechanism to rotate the rotary table can be depicted in Figure 12. Therefore, implementation of rotary table into Auto Tightening Front Cushion machine in detail can be depicted in Figure 13 which becomes the final design and will be manufactured.

Figure 12. Ratchet mechanism to rotate the rotary table

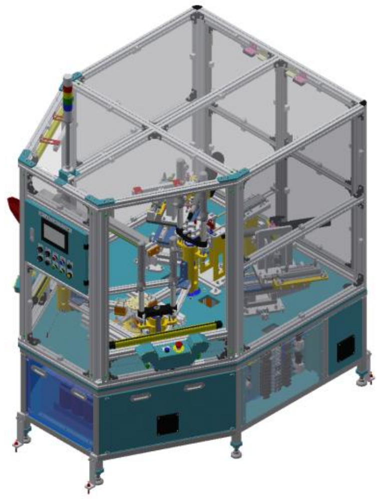


Figure 13. 3D View Auto Tightening Front Cushion Mc

4. Conclusion

Design of rotary table of Auto Tightening Front Cushion machine has conducted to satisfy the cycle time in bolt tightening into motorcycle front cushion. Through this function-oriented and VDI 2221 design methodology, Concept III of rotary table with main material of aluminium profile and pneumatic cylinder is chosen as the final design which is the optimal design especially considering the function and economical cost. The design strength checking is conducted by analysing the Von Mises stress, deflection, and safety factor and results the design satisfying the design standard procedure and can be concluded safe for manufacturing since it has minimum safety factor of 3.19 under combination load. Furthermore, FESTO round pneumatic cylinder with DSNU-40-250-PPV-A type is chosen as main drive to rotate the rotary table of Auto Tightening Front Cushion machine.

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