Manufacturing Process Planning of Concrete Mixer Driving System on 3D Concrete Printing Machine for Civil Buildings

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Keywords: 3D Concrete Printing Machine, Concrete Mixer, Manufacturing Planning.

Abstract: 3D Concrete Printing (3DCP) is a tool that functions to make a building construction automatically. The way 3DP works is to print material layer by layer to form a desired object. A 3D Concrete Printing (3DCP) consists of Mixer, Nozzle, X-axis Pillar, Y-axis Pillar, and Z-axis Pillar. A concrete mixer on the 3DCP machine is a tool that functions to mix cement, aggregate, and water homogeneously to form concrete to be distributed and printed. Generally, the concrete mixer has 4 part-functions, namely the drive function, the container function, the stirring function and the frame function. The planning of the construction of a concrete mixer driving system is expected to produce the design and manufacturing stages of the concrete mixer driving system that can rotate the container system to mix geopolymer cement, aggregate, and water so as to form geopolymer cement concrete with good homogenization that can meets the needs of geopolymer cement concrete to be printed.

1 INTRODUCTION

Additive Manufacturing (AM) is one of the methods where in the process the addition of material is carried out to make the desired shape. AM is a formal term for what is called rapid prototyping (RP) and what is popularly called 3D Printing (3DP) (Gibson, 2015). The way 3DP works is to print the material layer by layer until it forms a desired object (Erfiansyah, 2020).

3D Concrete Printing (3DCP), is an innovative construction method that has recently been introduced to the construction industry and has proven to be profitable in terms of optimizing construction time, cost, design flexibility, and reducing errors and being environmentally friendly (Malaeb, 2019). Politeknik Manufaktur Bandung, which has a vision of becoming a leading institution in the education, development, and application of manufacturing technology, plans to design and manufacture a 3D concrete printing machine for civil buildings.

The main material in making buildings using 3D printing techniques is geopolymer cement mixed with water and aggregate, which will be printed layer by layer until after setting and hardening will form a geopolymer cement concrete according to the working area of 3D Concrete Printing.

Geopolymer cement is obtained from the mixing process of fly ash and activators in the form of NaOH (flakes) and Na2SiO3 (granules). Geopolymer cement must be stirred with water and aggregate to produce geopolymer cement concrete (Yasin, n.d.). The process of stirring or mixing geopolymer cement and water and aggregate cannot be done manually because manual stirring is not able to meet the needs of geopolymer cement concrete to be printed. From these problems, a tool is needed that can stir geopolymer cement, water and aggregate until it is mixed into geopolymer cement concrete. The tool used to agitate concrete is commonly called a concrete mixer (Wankhede, 2015). In this case, the author's focus is to make a plan for the manufacture of a concrete mixer driving system on a 3D concrete printing machine of civil buildings.

2 METHOD

In the planning process of making a concrete mixer driving system, there is a design process that adopts VDI 2221 design method. The VDI 2221 method is a method with a systematic approach to solving

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problems and optimizing the use of materials and technology. After the design process is completed, manufacturing process must be conducted according to completed design. The following is a complete flowchart of the manufacturing process planning.

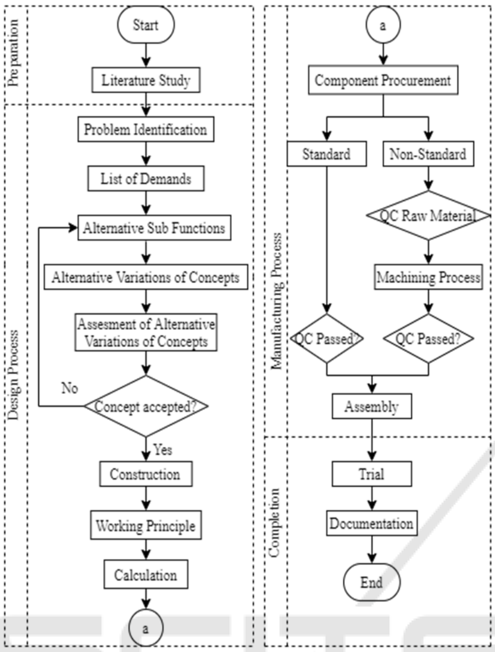


Diagram 1: Flow Process.

3 RESULT AND DISCUSSION

3.1 Design Process

3.1.1 Problem Identification

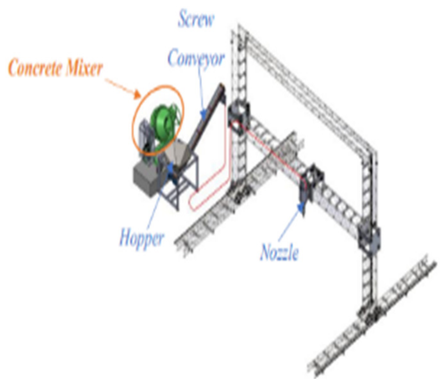


Figure 1: Concrete Mixer on 3DCP.

In 3D Concrete Printing technology, a tool is needed that cn do material stirring (it can also be called a concrete mixer) for then the material results in the form of geopolymer cement concrete is ready to be printed. There are several functions of parts of a concrete mixer. The author's focus is on the geopolymer cement stirring drive system.

3.1.2 List of Demands

Table 1: List of Demands.

Parameter	Specification	Priority
Manufacture	Standard components	*
	Existing components	**
	Borrowable components	*
Assembly	Easy assembly system	**
	Can be disassembled	*
Construction	Sturdy	*
	Simple	**
Kinematics	Mixer tank rotates at a speed of 40-50 rpm	*
Operation	Easy and ergonomic when operated	**
	Can be used for stirring geopolymer cement to form geopolymer cement concrete	*
Maintenance	Ergonomic during installation and maintenance	**
	Easy maintenance and repair	**
	Easy to clean	**
Safety	Safe operation	*
Cost	Minimum production cost	**
Resistance	Has a long lifetime	**
Aesthetic	Appealing visual	**

3.1.3 Alternative Sub Functions

Table 2: Alternative Sub Functions: Drive Source.

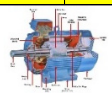
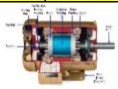
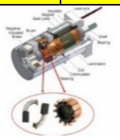
Alt 1 A1	Alt 2 A2	Alt 3 A3
 3 Phase Induction AC Motor	 1 Phase Induction AC Motor	 Motor DC
Excess		
• The use of electrical power is more efficient. • Suitable for use in industrial machinery.	• Construction is simpler. • Relatively cheaper.	• Speed and torque are easier to manage.
Deficiency		
• Relatively more expensive than 1 phase induction motors.	• It is more suitable for use in low-power and medium-load applications.	• The relative price is the most expensive. • Not suitable for large-power and high-speed applications.

Table 3: Alternative Sub Functions: First Transmission Element.

Alt 1 B1	Alt 2 B2	Alt 3 B3
Without transmission elements	 Pulleys and Belts	 Gearbox
Excess		
• Fewer and simpler components	• It can dampen shock loads, noise and vibration. • Easy design and flexible, do not require high tolerances. • Relatively cheaper.	• The transmission efficiency is higher because no slip occurs. • Mechanically stronger.
Deficiency		
• Put operation at risk.	• Not as compact as to gears.	• More complex design.

Table 4: Alternative Sub Functions: Second Transmission Element.

Alt 1 C1	Alt 2 C2	Alt 3 C3
 Straight Bevel Gear	 Worm Gear	 Spiral Bevel Gear
Excess		
• High transmission efficiency. • Construction is simpler.	• Large shock load capacity. • It's quieter.	• High transmission efficiency. • The load capacity is larger
Deficiency		
• Produces greater vibration and sound compared to spiral bevel gear.	• Lower transmission efficiency. • At risk during installation and use of the engine.	• Complex construction

3.1.4 Alternative Variations of Concepts

Alternative of concept variations will be assessed and the one with the highest value will be selected for further detailed designing.

Table 5: Morphology Box.

No.	Component	Var 1	Var 2	Var 3
1.	Drive motor	A1	A2	A3
2.	Transmission element 1	B1	B2	B3
3.	Transmission element 2	C1	C2	C3
Concept Variations		ACV1	ACV2	ACV3

The following are alternative results of variations in concepts:

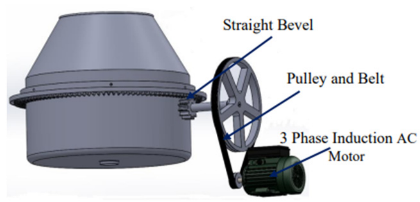


Figure 2: 1st Alternative of Concept Variations.

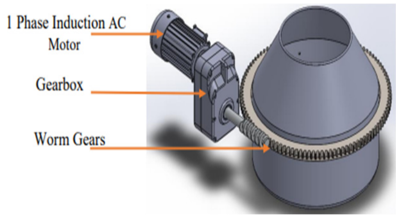


Figure 3: 2nd Alternative of Concept Variations.

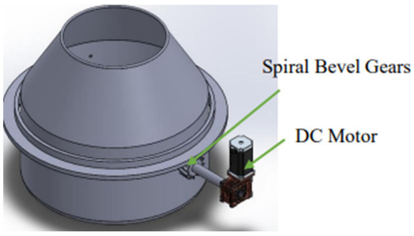


Figure 4: 3rd Alternative of Concept Variations.

All modeling variations are assessed according to:
- Nominal 5: Excellent, very achieved, and very easy.
- Nominal 4: Good, achieved, and easy.
- Nominal 3: Good enough, quite achieved, and quite easy.
- Nominal 2: Not good, less achieved, and less easy
- Nominal 1: Not good, not achieved, and not easy.

Table 6: Assessment of Alternative Concept Variations.

No.	Parameter	W	ACV 1		ACV 2		ACV 3	
			P	ST	P	ST	P	ST
1.	Manufacture	4	3	12	3	12	3	12
2.	Assembly	3	3	9	2	6	3	9
3.	Construction	5	3	15	3	15	2	10
4.	Operation	5	4	20	4	20	4	20
5.	Maintenance	3	4	12	3	9	3	9
6.	Safety	5	4	20	3	15	2	10
7.	Cost	3	4	12	3	9	3	9
8.	Aesthetic	2	3	6	4	8	3	6
9.	Resistance	4	3	12	4	16	2	8
Total Value		34	31	118	29	110	25	93
Percentage			86.7%		80.8%		68.4%	

3.1.5 Construction

This stage contains documents that include machine drawings, machine drawing details, a list of components, and other documents connected into a single entity. Here's the overall construction drawing of the selected 1st Alternative of Concept Variations (ACV1):

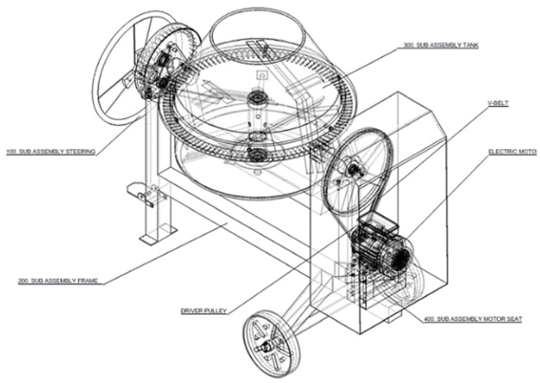


Figure 5: Assembly Construction of Concrete Mixer.

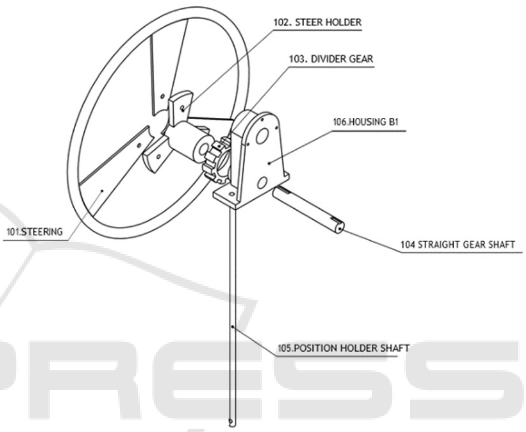


Figure 6: Construction of Sub-assy Steering.

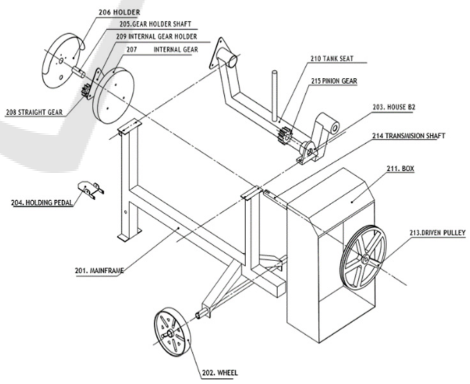


Figure 7: Construction of Sub-assy Frame.

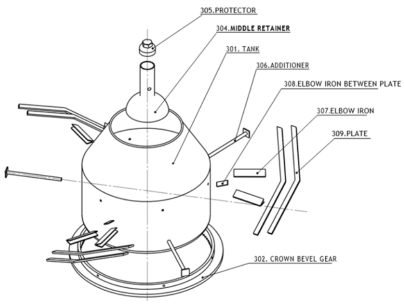


Figure 8: Construction of Sub-assy Tank.

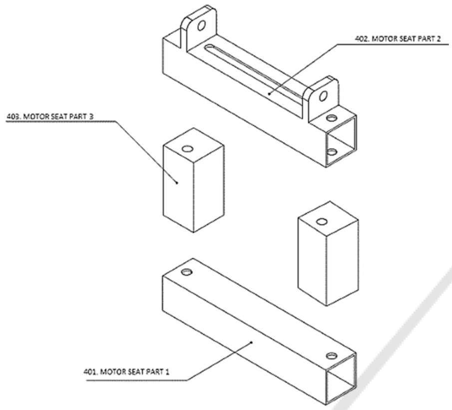


Figure 9: Construction of Sub-assy Motor Seat.

3.1.6 Working Principle

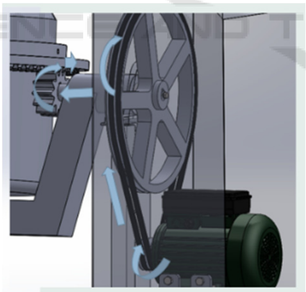


Figure 10: Working Principle Illustration.

The working principle of the concrete mixer driving system is that when the motor as the driving source is electrified, the motor shaft will rotate, the power and rotation of the motor shaft are then transmitted to the transmission system in the form of a pulley and belt, then passed to the transmission shaft. The rotation of the transmission shaft is passed to the pinion gear. The pinion gear rotates its pair, namely the crown gear that circles the mixer tank so that the mixer tank can rotate on its axis according to the rotation ratio to stir the geopolymer cement, water, and aggregate to form geopolymer cement concrete.

3.1.7 Calculation

Three Phase Induction AC Motor. The motor used is in accordance with the availability of components in Polman, with specifications:

- Motor output power = 3.7 kW
- Motor rev = 2890 rpm
- Loading torque = 13,21 Nm

Pulleys and Belts

a. Specifications of pulleys and belts

On the available concrete mixer, there are large pulley (driven pulley).

Known:

- Large pulley pitch diameters: $D_p = 450\ mm$
- Belt type required = V-Belt type A
- Number of belts required = 2 pieces

Asked:

- Small pulley pitch diameter?
- Shaft distance?
- Belt length?

Answer:

- Small pulley pitch diameter (d_p)

$$\frac{n_0}{n_1} = \frac{D_p}{d_p} \rightarrow \frac{2890}{436} = \frac{450}{d_p} \rightarrow d_p = 68\ mm \quad (1)$$

- Shafts' Distance Range (C)

The distance between two shafts must meet the following conditions:

$$C > 0{,}7\ (d_p + D_p) \text{ and } C < 2(d_p + D_p) \quad (2)$$
$$C > 0{,}7\ (68 + 450) \text{ and } C < 2(68 + 450)$$
$$C > 362{,}6 \text{ and } C < 1036$$

365 mm of shafts' distance is selected.

- Belt length (L)

$$L_{dth} = 2.C + \frac{\pi}{2}\left(d_p + D_p\right) + \frac{1}{4.C}\left(D_p - d_p\right)^2 \quad (3)$$
$$L_{dth} = 2.365 + \frac{\pi}{2}(68 + 450) + \frac{1}{4.365}(450 - 68)^2$$
$$L_{dth} = 1643{,}2\ mm$$

The belt length of the calculation result is adjusted to the standard on ISO 4184, the belt length is 1655(L_{dth}) (L_{dst}) mm, which is belt number A46.

- Distance between shafts (C)

The distance between shafts according to the standard belt length can be calculated by the formula:

$$C = \frac{2L_{dst} - \pi(D_p + d_p) + \sqrt{(2L - \pi(D_p + d_p))^2 - 8(D_p - d_p)^2}}{8} \quad (4)$$
$$C = \frac{2.1655 - \pi(450 + 68) + \sqrt{(2.1655 - \pi(450 + 68))^2 - 8(450 - 68)^2}}{8}$$
$$C = 371{,}81\ mm$$

b. Transmission efficiency

Based on calculations, it is known:

- Belt linear speed (V) =10,28 $^{m}/_{s}$
- Belt tight side tension (T_t) =347,28 N
- Belt saggy side tension (T_s) =95,79 N

Asked:

- Transmission efficiency?

Answer:

Determining torque

$$T = (T_t - T_s)r \quad (5)$$
$$T = (347{,}28 - 95{,}79)0{,}034$$
$$T = 8{,}56\ N.m$$

Determining the transmitted power

$$P_{out} = T \times \omega \quad (6)$$
$$P_{out} = T \times \frac{2\pi \times n_0}{60}$$
$$P_{out} = 8{,}56 \times \frac{2\pi \times 2890}{60}$$
$$P_{out} = 3009\ watt = 3\ kW$$

Determining transmission efficiency

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (7)$$
$$\eta = \frac{3}{3{,}7} \times 100\% = 81\ \%$$

Straight Bevel Gears. On the available concrete mixer, there are straight bevel gears in the form of pinion bevel gear and crown bevel gear.

Known:

- The rotation of the tank is desirable (the rotation of the crown gear): $n_2 \approx 45 - 50$ rpm, taken 48 rpm.
- Number of pinion gear: $Z_1 = 12$
- Number of crown gear: $Z_2 = 108$

Asked:

- Pinion bevel rotation to make the crown gear rotates 48 rpm?

Answer:

$$\frac{n_1}{n_2} = \frac{z_2}{z_1} \rightarrow \frac{n_1}{48} = \frac{108}{12} \rightarrow n_1 = 436\ rpm \quad (8)$$

Power to Rotates Mixer Tank. The power required to rotate the tank is the power needed by the pinion bevel gear to rotate the crown bevel gear.

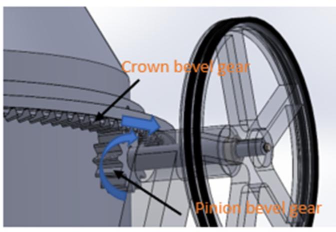


Figure 11: Illustration of pinion gear rotating crown gear.

Known:

- Power received by pinion gear from the pulley and belt transmission system = 3009 watts
- Pinion gear rotational speed (n1) = 436 rpm
- Crown bevel gear rotational speed (n2) = 48 rpm
- Mass of mixer tank= 98.58 kg
- Mass of crown gear = 32,40 kg
- Maximum capacity of tank load = 300 kg
- Diameter pitch pinion gear: $d_1 = 100{,}9$ mm
- Diameter pitch crown gear: $d_2 = 908{,}3$ mm

Asked:

- Power, force and torque on the pinion gear?
- The force, torque and power required to rotate the crown gear?

Answer:

- Power, force and torque on the pinion gear

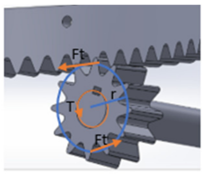


Figure 12: Illustration of the force that occurs in the pinion gear.

The power received by the pinion gear of the pulley and belt transmission system is:

$$P = 3009\ watt$$

Tangential force that occurs in the pinion gear that can be passed to the crown gear:

$$\mathrm{P} = \mathrm{T}.\omega \quad (9)$$
$$P = F_t . r . \frac{2\pi . n}{60}$$
$$F_t = \frac{P.60}{r\ .2\pi . n}$$
$$F_t = \frac{3009.60}{0{,}05\ .2\pi . 436}$$
$$F_t = 1318\ N$$

The torque required to rotate the pinion gear is:

$$T = F_t . r \quad (10)$$
$$T = 1318\ .0{,}05$$
$$T = 65{,}94\ Nm$$

- The force, torque and power required to rotate the crown gear

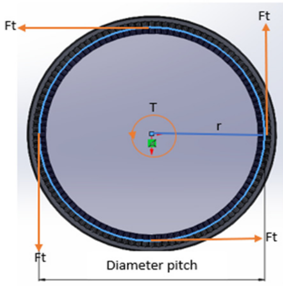


Figure 13: Illustration of the force that occurs in the crown gear.

Looking for tangential force, which is the force that acts on the crown gear to move in a circle in the tangential direction of a curved trajectory.

$$F_t = m.a_t \quad (11)$$
$$F_t = (m_{tank} + m_{crown\ gear} + m_{geopolymer}) \times (\alpha.r)$$
$$F_t = (98{,}58 + 32{,}40 + 300) \times (5{,}02 . 0{,}45)$$
$$F_t = 973{,}58\ N$$

After the tangential force is obtained, the torque, which is the force required for the crown gear to rotate on its axis at a distance r, can be calculated by the formula:

$$T = F_t.r \quad (12)$$
$$T = 973{,}58 . 0{,}45$$
$$T = 438{,}11\ Nm$$

The power required to rotate the crown gear can be calculated by:

$$P = T.\omega \quad (13)$$
$$P = 438{,}11 . \frac{2\pi.48}{60}$$
$$P = 2199\ watt \approx 2{,}2\ kW$$

- Conclusion:
  - Tangential force of crown gear < pinion gear
  - The power required by crown gear < the power that the pinion gear receives to be passed on.
  - If the calculation of torque with the rotation ratio is carried out, the torque on the pinion gear and on the crown gear < the loading torque of the motor which is 13.21 Nm.
  - It can be concluded that the pinion gear can rotate the crown gear, which means that the tank can rotate to stir the material that makes up the geopolymer cement concrete at the maximum capacity of the tank, which is 300 kg.

Composer Material of Geopolymer Cement Concrete. Based on the specifications of pulleys and belts, straight bevel gears, as well as the power ability of the motor to rotate the tank, the composition of the material that can be stirred by the concrete mixer is as follows:

Table 7: The composition of the stirred material.

No.	Identification
1.	Tank capacity
	• Tank capacity accommodates load at motor power 3.7 kW = 300 kg • It is known that the density of geopolymer cement is 2400 kg/mm^3, so the volume of geopolymer cement that can be accommodated is $= \frac{300}{2400} = 0{,}125\ m^3 = 125\ liter$
2.	The number of each constituent component of geopolymer cement concrete
	With a total capacity of 300 kg, each constituent component of geopolymer cement concrete is: 1. Geopolymer cement (30%) = 85 kg 2. Water (0,159xgeopolymer cement) = 13,5 kg 3. Coarse aggregate (3/5 x 70%) = 118.8 kg 4. Fine aggregate (2/5 x 70%) = 79.2 kg

3.2 Manufacturing Process

3.2.1 Component Procurement

Table 8: Component of Concrete Mixer Drive System.

No.	Component Name	Qty	Component Availability		
			Yes	No	
				Standard	Non
Electrical Components					
1.	3 phase AC motor	1	√		
2.	*Switch Button*	1		√	
3.	Magnetic contact	1		√	
4.	*Thermal overload relay*	1		√	
5.	*Pilot lamp off*	1		√	
6.	*Pilot lamp on*	1		√	
7.	NYA cable red	1		√	
8.	NYA cable black	1		√	
9.	NYA blue cable	1		√	
Mechanical Components					
1.	Motor seat	1			√
2.	*Driver pulley*	1		√	
3.	*Belt*	2		√	
4.	*Driven pulley*	1	√		
5.	Transmission shaft	1	√		
6.	Type A 8×7 parallel peg	2	√		
7.	Type A 10×8 parallel pegs	1	√		
8.	Bolt M8	1	√		
9.	*Washer*	1	√		
10.	Bearing 6205-ZR	1	√		
11.	*Housing bearing*	1	√		
12.	*Pinion bevel gear*	1	√		
13.	*Crown bevel gear*	1	√		

3.2.2 Machining Process Planning

The stages of the machining process are the sequence of processes to make raw material into the desired component. The following are Working process stages of non-standard components that need to be made, namely motor seat component.

Table 9: Working process stages of non-standard components.

No.	Component	Qty	Work Process
1.	Motor seat part 1	2	CG-HG-DR
2.	Motor seat part 2	2	CG-DR-MI-EW-HG
3.	Motor seat part 3	2	CG-DR

CG= Cutting grinding, DR=Drill, HG=Hand grinding, MI=Milling, EW=Electric welding

3.2.3 Assembly Planning

Assembly is a process of compiling and unifying several component parts into a tool or machine that has a certain function. These assembly activities include drafting, placing, fastening, and measuring. The following are the assembly stages of the drive system on the concrete mixer:

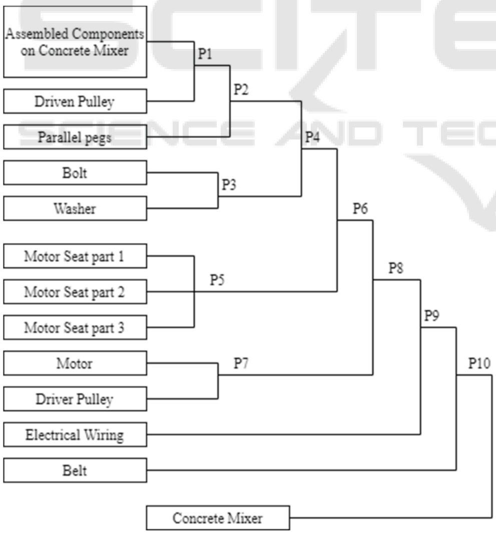


Diagram 2: Component Assembly Diagram of Concrete Mixer Driving System.

3.2.4 Trial

The trial stage is carried out to ensure that the concrete mixer can be used according to its function.

This aims to determine the tank's ability to stir geopolymer material, so it is expected that after the trial stage, what can be obtained is the data on the ideal capacity of geopolymer material that can be stirred by concrete mixer and the time required to achieve homogenization of materials.

4 CONCLUSIONS

The working principle of the concrete mixer driving system is that when the motor as the driving source is electrified, the motor shaft will rotate, the power and rotation of the motor shaft are then transmitted to the transmission system in the form of a pulley and belt, then passed to the transmission shaft. The rotation of the transmission shaft is passed to the pinion gear. The pinion gear rotates its pair, namely the crown gear that circles the mixer tank so that the mixer tank can rotate on its axis according to the rotation ratio to stir the geopolymer cement, water, and aggregate to form geopolymer cement concrete.

In planning the manufacture of this concrete mixer, the process begins with the design method of VDI 2221, then continues with the planning process, then continues with the process of procurement of components. After that, the process of machining, assembly, trial and document collection should be carried out.

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