REDESIGN OF MANUFACTURING PROCESS FOR GEAR TRANSMISSION BOX COMPONENT OF HAND TRACTOR

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ABSTRACT

Design for Manufacture (DfM) is one of approach in product design development. It is integration of art design, material and process choosing in quality consideration. Gear Transmission Box (GTB) component of hand tractor is one of main component that compile hand tractor. It's base component, other components are connected to it. It was produced in combination of casting-machining process and its manufacturing cost is the second highest that cause high production cost. To solve it, development or redesign of fabrication is needed. To realize it, load and force it detained have to be known, and than create alternatives design and process using DfM approach that yield cheaper design but still strong enough for detaining operation load. In this research, two alternatives were resulted. Both are using St 37 plate as base material and combination plate metal forming, welding and machining as basic process. The First redesign reduces manufacturing cost 11.75%, and the second 27%. From this research, it can be concluded that in design stage, there are a lot of potential things can be improved and developed that make production cheaper.

Key words : Design for manufacture, manufacturing cost, load analysis

1. INTRODUCTION

Currently, the industrial competition becomes more complex. The companies compete each other by relying on their own potential to get and conquer the market. This condition pushed them to do continuous improvement for their product that more user/customer friendly in material, weight or technology offered the price that could be reached by customer. The main contributor of manufacture cost is design factor. In fact, quite often more than 80% of the manufacturing cost of a product is determined by this factor, yet manufacturing is not involved (Anderson 2007).

One of the approach methods in product design development is Design for Manufacture (DfM). DfM is a systematic and comprehensive design approach that considering material, manufacture method, design process, assembly, testing and quality.

In agricultural world, Farm processing plant in a short time will improve the productivity. One of needing in farm processing is agricultural equipment mechanized. In Indonesia, One other have there is hand tractor. But it will become the barrier when price of hand tractor on farmer is too high. One of cause is the level of production cost. It was happen in hand tractor product of PT Agrindo one of notable hand tractor producer in Indonesia. Based on their analysis, Gear

Transmission Box (GTB) is one of main factor which increase production cost. It is the second highest of manufacturing cost from seven components. Gear transmission box is produced using casting process. It can't be produced in mass production. So its process and design must be developed.

By Using DfM concept, in this paper will be shown the process of GTB design development. Here, loads that GTB detained are calculated and become main consideration as a quality parameter. The best design is the cheaper design.

2. PRODUCT DEVELOPMENT AND DESIGN CONCEPT

DfM Definition

There are some definitions about Design for Manufacture (DfM). Kalpakjian (1989) define it as a comprehensive approach to produce things and integrate design process with choosing material and manufacturing method, process planning, machine and tools. And it was defined more by Anderson (2007). He defined it as the process of proactively designing products to (1) optimize all the manufacturing functions: fabrication, assembly, test, procurement, shipping, delivery, service, and repair, and (2) assure the best cost,

quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction. Based on definitions above, in a few word Design for Manufacture is integration of art design, material and process choosing in quality consideration

DfM Concept

From a manufacturability perspective, DFM approach help avoid the “disconnect” that often occurs when the design team puts forth a product that cannot be manufactured. DFM benefits the design team by allowing them to explore alternatives in processes and materials, while showing the cost impact of each decision. This allows designers to improve the manufacturability of their product through simplification. (Andrews, 2006)

Marginally Ulrich and Eppinger (2000) said that there are five step in running DfM approach;

1. Approximating manufacturing cost
There are three category of manufacturing cost, they are component cost, assembly cost and overhead cost.
2. Lessening component cost
There are Some chance that can be applied to lessening cost; simplification part design, allow not so good surface refining, using cheaper material, using more efficient machine, tools and control, etc.
3. Lessening assembling cost
Assembly cost can be calculated based on labor cost and processing cost which is quantifying from assembly material cost and tooling cost.
4. Lessening overhead cost.
It can be done by minimize systemic complexity.
5. Considering influence of decision DfM to another factors
Factors that have to be known are; development time, development cost, product quality, the external factors including reuse component and life time cost.

Load Analysis

Load analysis is used to know how much and how big force/load that has to be shored up. It is use full in measuring design strength.

Eccentrically loaded rivets

Making use of law of static, which says that a force may be moved to a parallel coplanar position

by replacing it by an equivalent force and couple, F (solid line) is replaced by the equivalent force F (dotted), acting through the center of gravity of rivet group, and equivalent couple Fe like shown in. F (dotted) are apportionment to each rivet given by,

$$F_1(\text{dotted}) = F_2(\text{dotted}) = F_n(\text{dotted}) = \frac{F}{n} \quad (1)$$

And Forces (T_j) caused by couple Fe , given by

$$T_j = \frac{Fed_j}{\sum_{k=1}^n d_k^2} \quad (2)$$

Where e is horizontal distance to center of gravity of rivet system in meter, F is eccentric force that causes load in rivets systems in newton and d_k is variable that show distance each rivet to center of gravity of rivet systems in meter.

Load in bearing caused gear and shaft rotary

Load in bearing that caused by power transmitted consist of two forces. Tangential force (F_t) and radial force (F_r) (Deutschman, 1975). Tangential direction is go to center of bearing but radial force direction is opposite with radial movement. Both are given by

$$F_r = F_t \tan \Phi \quad (3)$$

$$F_t = \frac{(hp)(33000)}{V_p} \quad (4)$$

And Pitch velocity (V_p) is given by

$$V_p = \frac{\pi dn}{12} \quad (5)$$

Torsion (T) And power that transmitted (hp) given by

$$hp = \frac{Tn}{63000} \quad (6)$$

Where Φ is pressure angle of gear in degree, hp is power transmitted by gear in horse power, torsion (T) in inches-pound, angular velocity n in rpm, gear diameter d in inches, V_p in ft/min, F_t and F_r in lbf.

Machining

Cutting time of freis process

In his book, Taufiq (1993) was explain that cutting time (t_c , min) is depend on length of cutting track (l_t , mm) and cutting speed (v_f , mm/min) that given by,

$$t_c = l_t / v_f \quad (7)$$

$$l_t = l_v + l_w + l_n \quad (8)$$

where l_v is starting track in mm and l_n is finishing track in mm.

$$l_v \geq \sqrt{a(d-a)} ; \text{ for horizontal freis}$$

$$l_v \geq 0 ; \text{ for vertical freis}$$

$$l_n \geq 0 ; \text{ for horizontal freis}$$

$$l_n = d/2 ; \text{ for vertical freis}$$

Cutting time of drilling and boring process

Similar with freis process, Taufiq (1993) was explain about cutting time of drilling and boring process is given by

$$f_z = v_f / (n \cdot z) ; z = 2 \quad (9)$$

Cutting time (t_c , min) 4.:

$$t_c = l_t / v_f \quad (10)$$

$$l_t = l_v + l_w + l_n \quad (11)$$

Where v_f is cutting speed in mm/min, n is number of tools, l_v is starting track in mm and l_n is finishing track in mm

Machining total operation time

for each machining process, machining total operation can be found by adding non productive time (t_a), tool changing time (t_d) and cutting time (t_c).

$$t_o = t_a + t_d + t_c \quad (12)$$

Force Needed in Pressing Process

Force needed for percing and blanking (F_s) some plat material that have cutting periphery L_s and thickness S_o are given by:

$$F_s = L_s \cdot S_o \cdot K_s \quad (13)$$

(PN RAO, Manufacturing Technology)

Where K_s is shift tension that is gotten from ultimate strength of material $\{0,8 \sigma_u\}$ (kg/mm²)

Minimum Radius (R_{min}) in Drawing Process

Necking criteria

This Necking causes dilution of part of metal at bent area. Necking happen when elongation or lengthening in external fiber of specimen e_t that exceeding the uniform elongation of material e_u from unaxial tensile test.

$$e_t = \frac{1}{\left(\frac{2 \cdot R}{s_o}\right)} \leq e_u \quad (14)$$

So, minimum radius R_{min} can be known by

$$R_{min} = \frac{s_o}{2} \left(\frac{1}{e_u} - 1 \right) \quad (15)$$

Where R is bending radius. s_o is material thickness. And e_u can be calculated from $e_u = (exp. n - 1)$. n is got from tensile test.

Cracking criteria.

Cracking cause the rip at bent area. The following Equation determined by q that is reduction of longitudinal section of material that resulted by f unaxial tensile test.

For less ductile material, $q < 0,2$

$$R_{min} = s_o \times \left(\frac{1}{2 \cdot q} - 1 \right) \quad (16)$$

For ductile material, $q > 0,2$

$$R_{min} = s_o \times \frac{(1 - q)^2}{(2 \cdot q - q^2)} \quad (17)$$

Strain factor

Good drawing design has to pass strain factor. strain of design e_s must be less than elongation of material e_u from unaxial tensile test.

$$e_s = \frac{1 - \cos \alpha}{\frac{c}{w} \pm 1} \leq e_u \quad (18)$$

Where α is bending angle. c is inner radius of bending line. w is flange width.

3. REDESIGN PROCESS

Initial Design

Initial GTB consist of two part, left hand side (GTB LH) and right hand side (GTB RH). It is shown in Figure 1.

Figure 1. Initial gear transmission box

GTB are produced in combination casting and machining process. It mean after casting finished, GTB should be entered seven machining step. Process sequences GTB RH and LH are shown in figure 2 and 3

Figure 2. Flow Process Diagram of GTB RH

Figure 3. Flow Process Diagram of GTB LH

The using of machine and each cost rate are shown in Table 1. process can be seen in figure 2 and 3.

Table 1. using and cost rate of machine

machine	Type	Process	cost rate (Rp/min)
vertical milling		5	24.1
horizontal milling	1a	2	50.1
	1b	3	50.1
	2a	6(RH)	50.1
	2b	6(LH)	50.1
drilling machine	Standard1	1	37.1
	Standard 2	4	37.1
	Radial	7	37.1

Manufacturing Cost

All of initial manufacturing costs were got from the company. Overhead cost decided by PT Agrindo 5% from material cost and 10% from machine, assembly and labor cost. Tabulation of manufacturing cost of initial GTB is shown in Table 2. assembly cost is zero because in this initial design there aren't assembly operation;

Table 2. Manufacture cost of initial GTB (Rp)

part name	material cost	machine cost	labour cost	assembly cost	overhead cost	manufacturing cost
GTB LH	144,500.0	11,149.3	30,917.3	0.0	11,431.7	197,998.2
GTB RH	143,500.0	9,229.0	26,224.2	0.0	10,720.3	189,673.5
total	288,000.0	20,378.3	57,141.5	0.0	22,152.0	387,671.7

Load Analysis

GTB detain loads from another main component of hand tractor. There are two kind of load, static and dynamic. Static loads are caused by weight of another component. There are Frame handle 22 kg, Frame engine dan engine 116 kg Rear hitch and plow 34 kg, floating wheel 52 kg and GTB their self 36 kg. dynamics by rotation of gear systems. Maximum load is the biggest resultant of dynamic and static load. By equation (1), (2), (3), (4), (5) and (6). Maximum load can be calculated. It is 57.39 kN in GTB RH.

Design 1

This design use ST 37 plate as material. Thickness of main body is 6 mm, main shaft cover and pulley shaft cover are 4.3 mm, secondary shaft is 2 mm. this design consist of 13 part each side. (shown in Figure 4)

Figure 4. Design 1 of GTB breakdown

Design 1 is produced in combination plate metal forming (drawing, piercing, shearing, banding and blanking), welding and machining. These operation were shown in Table 3 and 4. machine cost was calculated with multiply the machine cost rate (table 1) with machine operation time. Labour cost was got by multiply labour time with the labour cost rate (Rp 122.45).

Table 3. Production operation list of design 1

Gear Transmission Box LH			
Operation	Machine	Machine cost (Rp)	labour cost (Rp)
main body forming (A and B)	hidrolic pressure	6552.9	2371.9
main body forming (C)	hidrolic pressure	8586.1	3107.8
main shaft cover forming	hidrolic pressure	4773.4	1727.8
secondary shaft cover forming	hidrolic pressure	4330.2	1567.4
pulley shaft cofer forming	hidrolic pressure	4712.5	1705.7
tube support cutting	band SAW Mega	659.3	2755.1
Full side freis mill	vertical milling	1903.4	5167.4
Drilling 2 pen holes	standard 1 drilling	827.4	2730.6
Boring+chamfering 5 holes together	horizontal 2 milling	456.4	1115.5
Drilling oil tapping	radial drilling	217.1	716.3
Drilling oil sprue	radial drilling	217.1	716.3
Drilling 8 holes Ø 7	standard 1 drilling	280.1	924.5
Drilling 6 holes Ø 8	standard 2 drilling	254.2	838.8
Drilling 6 holes Ø 10	standard 1 drilling	253.8	837.6
Drilling 15 holes Ø 8	standard 2 drilling	369.9	1220.8
freis main shaft cover	horizontal 2 milling	314.7	769.0
freis pulley shaft cover	horizontal 2 milling	296.1	723.7
drill 6 holes main shaft cover	standard 2 drilling	252.3	832.7
drilling 3 holes secondary shaft cover	standard 1 drilling	213.3	704.1
Drilling 6 holes pulley shaft cover	standard 2 drilling	252.3	832.7
LH-Total		35722.5	31365.6
Gear Transmission Box RH			
Operation	Machine	Machine cost (Rp)	labour cost (Rp)
main body forming (A and B)	hidrolic pressure	6552.9	2371.9
main body forming (C)	hidrolic pressure	8586.1	3107.8
main shaft cover forming	hidrolic pressure	4773.4	1727.8
secondary shaft cover (RH) forming	hidrolic pressure	4621.2	1672.7
tube support cutting	band SAW Mega	659.3	2755.1
Full side freis mill	vertical milling	1903.4	5167.4
Drilling 2 pen holes	standard 1 drilling	827.4	2730.6
Boring+chamfering 5 holes together	horizontal 2 milling	456.4	1115.5
Drilling 6 holes Ø 7	standard 1 drilling	254.2	838.8
Drilling 6 holes Ø 8	standard 2 drilling	254.2	838.8
Drilling 6 holes Ø 10	standard 1 drilling	253.8	837.6
Drilling 15 holes Ø 8	standard 2 drilling	369.9	1220.8
freis main shaft cover	horizontal 2 milling	314.7	769.0
drill 6 holes main shaft cover	standard 2 drilling	252.3	832.7
drilling 6 holes secondary shaft cover	standard 1 drilling	251.9	831.4
LH-Total		30331.0	26817.8
LH-RH Total		66053.4	58183.3

Table 4. Assembly Operation List of Design 1

Gear Transmission Box LH			
Assy Operation	Machine	Machine cost (Rp)	labour cost (Rp)
welding main body B-C Assy	CO new K200 855502 weld	1171.8	2894.6
welding main body A-(BC) Assy	CO new K200 855503 weld	1052.3	2601.1
welding 6 part tube support Assy	CO new K200 855502 weld	308.5	757.5
LH-Total		8785.59	
Gear Transmission Box RH			
Assy Operation	Machine	Machine cost (Rp)	labour cost (Rp)
welding main body B-C Assy	CO new K200 855502 weld	1171.8	2894.6
welding main body A-(BC) Assy	CO new K200 855503 weld	1052.3	2601.1
welding 6 part tube support Assy	CO new K200 855502 weld	308.5	757.5
LH-Total		8785.59	
LH-RH Total		17571.2	

Table 5 below show us that using equation (18) Forming operations in Design 1 can be done. ($e_u=0.1654$, Subekti, 2004)

Table 5. Strain factor of Design 1

part name	strain factor	e_u	conclusion
main shaft cover	0.097631073	0.1654	no failure
pulley shaft cover	0.140079366	0.1654	no failure
secondary shaft cover	0.033795371	0.1654	no failure

Manufacturing cost is calculated by summing material, machine of production, labour of production, assembly and overhead cost. Over head cost was calculated similarly method with initial design. material cost is accumulated from plates cost, welding filler and tube cost. Assembly cost is sum of machine cost and labour cost in assembly operation.

Table 6. Manufacturing cost of design 1

part name	material cost	machine cost	labour cost	assembly cost	Overhead cost	manufacturing cost
GTB LH	89,931.2	35,722.5	31365.6	8785.59	12,083.9	177,888.8
GTB RH	87346.34	30,331.0	26,817.8	8785.59	10,960.7	164,241.4
total	177,277.6	66,053.4	58,183.3	17,571.2	23,044.7	342,130.2

Design 2

Design 2, as like as design 1 using ST 37 material. But there is deference in main body. In this design, main body consist of a part that. Thickness of main body 3.2 mm. there is supporting plate 8 mm thickness in every side of GTB. This design consists of 11 parts in a side. (shown in Figure 4)

Figure 5. Design 2 of GTB breakdown

In this design similarly design 1, GTB are produced in combination metal forming, welding and machining too. There are 5 metal forming operations, 16 machining and 2 assembly operations in GTB LH. And in other side there are 4 metal forming operations, 12 machining and 2 assembly operations. All of them are shown in table 7 and 8 below.

Table 7. Production operation list of design 2

Gear Transmission Box LH			
Operation	Machine	Machine cost (Rp)	labour cost (Rp)
main body forming	hidrolic pressure	5839.1	2113.5
plate support foming	hidrolic pressure	5368.8	1943.3
main shaft cover forming	hidrolic pressure	4773.4	1727.8
secondary shaft cover (LH) forming	hidrolic pressure	4330.2	1567.4
pulley shaft cofer forming	hidrolic pressure	4712.5	1705.7
tube support cutting	band SAW Mega	659.3	2755.1
Full side freis mill	vertical milling	1903.4	5167.4
Drilling 2 pen holes	standard 1 drilling	827.4	2730.6
Full side freis mill	vertical milling	411.8	1118.0
Boring+chamfering 5 holes together	horizontal 2 milling	469.0	1146.1
Drilling oil taping	radial drilling	216.7	715.1
Drilling oil sprue	radial drilling	216.7	715.1
Drilling 8 holes Ø 7	standard 1 drilling	290.5	958.8
Drilling 6 holes Ø 8	standard 2 drilling	258.6	853.5
Drilling 6 holes Ø 10	standard 1 drilling	251.9	831.4
Drilling 15 holes Ø 8	standard 2 drilling	365.5	1206.1
freis main shaft cover	horizontal 2 milling	314.7	769.0
freis pulley shaft cover	horizontal 2 milling	296.1	723.7
drill 6 holes main shaft cover	standard 2 drilling	252.3	832.7
drilling 3 holes secondary shaft cover	standard 1 drilling	213.3	704.1
Drilling 6 holes pulley shaft cover	standard 2 drilling	252.3	832.7
LH-total		32223.5	31117.0
Gear Transmission Box RH			
Operation	Machine	Machine cost (Rp)	labour cost (Rp)
main body forming	hidrolic pressure	5839.1	2113.5
plate support foming	hidrolic pressure	5368.8	1943.3
main shaft cover forming	hidrolic pressure	4773.4	1727.8
secondary shaft cover (RH) forming	hidrolic pressure	4621.2	1672.7
tube support cutting	band SAW Mega	659.3	2755.1
Full side freis mill	vertical milling	1903.4	5167.4
Drilling 2 pen holes	standard 1 drilling	827.4	2730.6
Full side freis mill	vertical milling	411.8	1118.0
Boring+chamfering 5 holes together	horizontal 2 milling	469.0	1146.1
Drilling 6 holes Ø 7	standard 1 drilling	258.6	853.5
Drilling 6 holes Ø 8	standard 2 drilling	258.6	853.5
Drilling 6 holes Ø 10	standard 1 drilling	251.9	831.4
Drilling 15 holes Ø 8	standard 2 drilling	365.5	1206.1
freis main shaft cover	horizontal 2 milling	314.7	769.0
drill 6 holes main shaft cover	standard 2 drilling	252.3	832.7
drilling 3 holes secondary shaft cover	standard 1 drilling	251.9	831.4
RH - total		26826.8	26552.1
RH-LH Total		59050.4	57669.1

Table 8. Assembly operation list of design 2

Gear Transmission Box LH			
Assy Operation	Machine	Machine cost (Rp)	labour cost (Rp)
welding plate support Assy	CO new K200 855502 welding	520.6	1297.3
welding 6 part tube support Assy	CO new K200 855503 welding	294.7	757.5
LH-total		2870.1	
Gear Transmission Box RH			
Assy Operation	Machine	Machine cost (Rp)	labour cost (Rp)
welding plate support Assy	CO new K200 855502 welding	520.6	1297.3
welding 6 part tube support Assy	CO new K200 855503 welding	294.7	757.5
RH - total		2870.1	
RH-LH Total		5740.2	

All plate metal forming operation can be done and they aren't caused crack and failure. (Table 9) all of strain factor are lower than elongation unaxial.

Table 9. Strain factor of design 2

part name	strain factor	ϵ_u	conclusion
main body	0.143575107	0.1654	no failure
main shaft cover	0.097631073	0.1654	no failure
pulley shaft cover	0.140079366	0.1654	no failure
secondary shaft cover	0.033795371	0.1654	no failure

Manufacturing cost of design 2 are shown in Table 10 below;

Table 10. Design 2 Manufacturing cost

part name	material cost	machine cost	labour cost	assembly cost	overhead cost	manufacturing cost
GTB LH	70,552.9	32,223.5	31,117.0	2,870.1	10,148.7	146,912.2
GTB RH	67,968.0	26,826.8	26,552.1	2,870.1	9,023.3	133,240.3
Total	138,520.9	59,050.4	57,669.1	5,740.2	19,172.0	280,152.5

4. DISCUSSION

In cost parameter, the biggest reduction of two design for initial design are in material cost. Even design 2 reduces material cost till 51.9%. Initial Design manufacturing cost is Rp 387,671.7. Design 1's is Rp 342,130.2. Design 2's is Rp 280,152.5. Overall, Design 2 performs the lowest cost between the alternatives. It reduces total manufacturing cost until 27%, it is bigger than Design 1 that only 11.75% (figure 6).

Figure 6. Manufacturing cost comparison chart

About the loads that are detained by GTB, maximum load (F_m) is 57.9 kN or 5,7 ton. Smallest longitudinal section wide of design 2 are in plate support. The size is;

$$L = 8 \text{ (thickness)} \times 90 \text{ (width)} \\ = 720 \text{ mm}^2$$

With yield strength (technique) of ST 37 = 366.6 N/mm² (Subekti, 2004) and safety factor 10%, maximum load that can be detained by desain 2 is

$$F_{\text{platemax}} = 720 \times (1-10\%) \times 366.6 \\ = 237556.8 \text{ N} = 237.6 \text{ kN}$$

Because of $F_{\text{platemax}} > F_m$, technically Design will be safe.

About the investment, company needn't buy pressure machine for metal forming operation. Using equation (13), Maximum force to forming is 497 ton (piercing plate support). Company have hydraulic pressure machine, with the specification below;

Machine name : MINCANG type MCD 75 Hp

Dimension : 6700 x 4650 x 3800 mm

Capacity : 500 ton / 8 mm

Power : 75 Hp - 380 Volt - 50 Hz

Pressure : 210 Kg / cm²

Investment is needed to make dies of pressure machine for metal forming. It is about 14 – 15 milion rupiahs or US\$ 1,522.- US\$ 1,630 (with 1 US\$ = Rp 9,200.-) for five dies. How small amount of it if compared with improvement that was resulted. This methods could be done by the company because the aplication of this design will affect positively to a whole process.

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