Rigid Logged Coupling: An Improved Coupling with Less Material and Low-Stress Concentration

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Abstract The paper is about a new coupling design that can be used to connect two shafts in the same line without any axial or angular misalignment. The goals of the new design are to reduce the amount of material required to produce other couplings and reduce the chances of failure due to different stress distribution patterns. Rigid flanged coupling is used as a reference for comparison. The design consists of mainly three parts body, pins and logs (strips of metal used to connect the body). The holes are done on outer surfaces of the hexagonal or a square prism of each body while one surface of each body faces each other. The logs are used to join the two bodies with the help of pins in the holes. The coupling is designed using Autodesk Fusion 360. Proper mathematical analysis of the couplings is done to get the difference in the material used. This design can be used to connect both, shafts with the same diameter or shafts with different diameters. The design has less stress concentration around holes and in whole design in general and is similar in the manufacturing process as the presently available couplings. For the safety of the operator or user, the coupling is covered with a protective case to avoid the failed parts (if any) to hit the operator or the user. The dimensions are found using stress analysis and considering the modes of failure for each section of the part. Shear and tensile failure have been considered at the parts of the assembly. The bending effect has also been considered for parts wherever adequate. The stress analysis results have also been found out using Autodesk Fusion 360. To observe the effects and results of stress analysis, similar working conditions have been simulated with the coupling designed in Autodesk Fusion 360.

Keywords Coupling · Rigid · Logged · Design

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1 Introduction

Most of the rigid couplings popularly in use today comprise two flanges attached to each other and transmitting motion, power and torque. This particular method of coupling is required to join two shafts that are one from the power receiving end and the other power generation end. The flanges, for manufacturing, require a lot of metal and due to the various methods by which they are joined, stress is also concentrated to certain parts which lead to failure of the flanges or a high factor of safety needs to be considered.

The use of the designed coupling is to use less material considering the same factor of safety and even more reduction of material when less factor of safety is considered due to the reduction in stress concentration in power transmission areas.

2 Design Process

2.1 Logged Coupling

See Figs. 1 and 2.

2.2 Empirical Relations [1]

Empirical relations are mostly the pre derived, assumed and universally accepted relations. In this derivation, the empirical relations are kept the same as rigid flanged coupling.

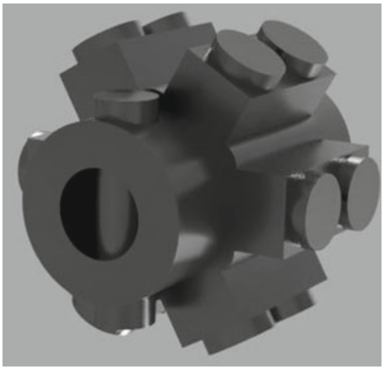


Fig. 1 Full assembly

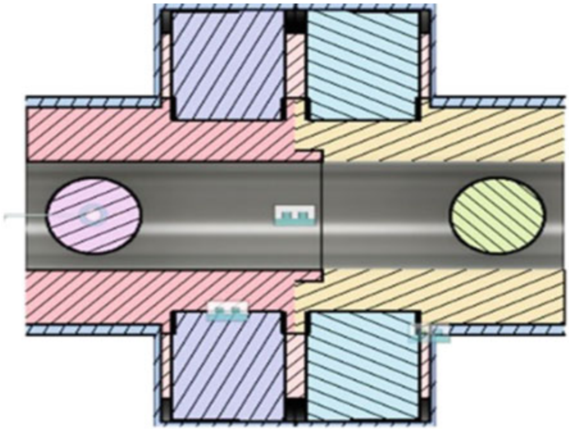


Fig. 2 Section of full assembly

$$d = \sqrt[3]{\frac{16M}{\pi\tau}} \tag{1}$$

$$d_h = 2d \tag{2}$$

$$l_l = d \tag{3}$$

$$l_h = 1.5d \tag{4}$$

$$t = d \tag{5}$$

$$D_{\text{in}} = 2.5d \tag{6}$$

$$b_1 = 1.25d = \frac{D_{\text{in}}}{2} \tag{7}$$

$$d_1 = \frac{0.5d}{\sqrt{N}} \tag{8}$$

In the above relations, the terms used have the following meanings (Table 1):

d Diameter of the shaft
M Moment
τ Torque to be transmitted
d_h Diameter of the hub of flange
l_l Length of the flange
l_h Length of the hub
t Thickness of the flanges
D_{in} Inner diameter of the flange (Flanged coupling)

Table 1 Values for no. of side of polygon with respect to diameter in mm

Value of N	d start	d end
3, 4	0	20
6	20	80
8	80	120
10	120	–

All the calculations for rigid logged coupling have been done for diameter size 20–80, that is, $N = 6$

b_1 Size of outer edge
d_1 Diameter of pins.

2.3 Shear Failure of Log

See Fig. 3.

$$\textbf{Shear area} = \frac{\boldsymbol{b}}{\mathbf{2}} * \boldsymbol{h}$$

$$\tau = \frac{P}{\frac{b}{2} * h} \tag{9}$$

$$P = \mathrm{M} / \left(\frac{D_{\mathrm{in}}}{2} * \frac{\sqrt{3}}{2} \right) \tag{10}$$

$$b \le b_1 \tag{11}$$

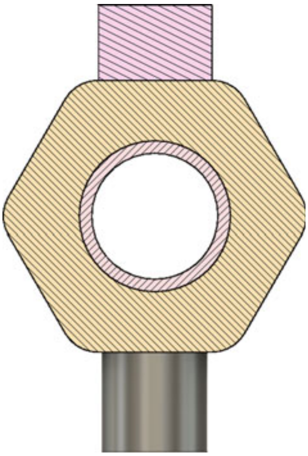


Fig. 3 Maximum shear area of log

$$\tau = \mathrm{M}/\left\{\left(\frac{D_{\text{in}}}{2} * \frac{\sqrt[2]{3}}{2}\right) * \left(\frac{b}{2} * h\right)\right\} \tag{12}$$

$$b * h = 8\mathrm{M}/\left\{2.5 * d * \sqrt{3} * \tau\right\} \tag{13}$$

$$\tau * \frac{\pi}{4} * d_1^2 = P \tag{14}$$

$$d_1^2 = \mathrm{M}/\tau * \left(\frac{D_{\text{in}}}{2} * \frac{\sqrt[2]{3}}{2}\right) * \frac{\pi}{4} \tag{15}$$

$$d_1 = 4 * \sqrt{\mathrm{M}/\left\{\tau * \left(2.5 * d * \sqrt{3}\right) * \pi\right\}} \tag{16}$$

In the above relations the new terms used has following meanings:
b: Breadth of the log.

2.4 If Pins Are Loosely Kept [Bending Consideration]

See Fig. 4.

$$M = P * \frac{l_b}{2} \tag{17}$$

$$P = \frac{M}{\frac{D_{\text{in}}}{2} * \frac{\sqrt{3}}{2}} = \frac{4M}{2.5 * d * 2 * \sqrt{3}} \tag{18}$$

$$M_b = \frac{4Ml_b}{2.5 * d * 2 * \sqrt{3}} \tag{19}$$

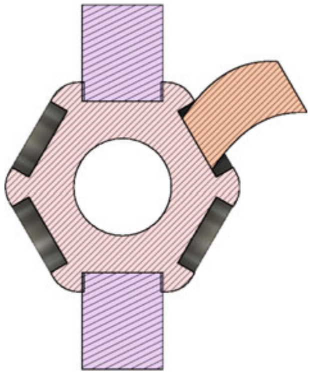


Fig. 4 Bending of pin

$$\sigma_b = \frac{32M_b}{\pi d_1^3} \tag{20}$$

$$\sigma_b = \frac{32}{\pi d_1^3} * \frac{4M}{2.5 * d * 2 * \sqrt{3}} \tag{21}$$

$$d_1 = \sqrt[3]{\frac{64 * M * l_b}{2.5 * \sqrt{3} * d * \pi * \sigma_b}} \tag{22}$$

2.5 Shear Stress in Connecting Pin

See Fig. 5.

$$\tau = \mathrm{P}/\left\{\frac{\pi}{4} * d_2^2\right\} \tag{23}$$

$$\tau = \mathrm{M}/\left\{\frac{d_h}{2} * \frac{\pi}{4} * d_2^2\right\} \tag{24}$$

$$\therefore d_2 = \sqrt{4\mathrm{M}/\{\pi * d * \tau\}} \tag{25}$$

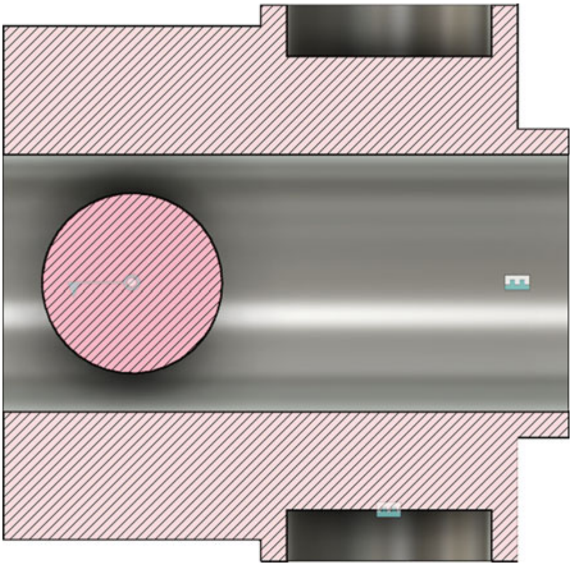


Fig. 5 Shear area of connecting pin

3 Simulation Data and Results

The rigid logged coupling and the rigid flanged coupling were simulated in Autodesk Fusion 360 under different conditions; the conditions of rigid logged coupling having more tough testing conditions.

The conditions and results are listed below for both rigid flanged and rigid logged coupling.

3.1 General Settings

See Tables 2, 3, 4 and 5.

Table 2 General

Contact tolerance	0.1 mm
Remove rigid body modes	No

Table 3 Mesh

Average element size (% of model size)	
Solids	10
Scale mesh size per part	No
Average element size (absolute value)	–
Element order	Parabolic
Create curved mesh elements	Yes
Max. turn angle on curves (deg.)	60
Max. adjacent mesh size ratio	1.5
Max. aspect ratio	10
Minimum element size (% of average size)	20

Table 4 Adaptive mesh refinement

Number of refinement steps	0
Results convergence tolerance (%)	20
Portion of elements to refine (%)	10
Results for baseline accuracy	Von Mises stress

Table 5 Materials

Component	Material	Safety factor
Component 1:1	Steel	Yield strength

Table 6 Mesh

Type	Nodes	Elements
Solids	4800	2682

Table 7 Pressure1

Type	Pressure
Magnitude	4.8 MPa

Table 8 Pressure2

Type	Pressure
Magnitude	1.896 MPa

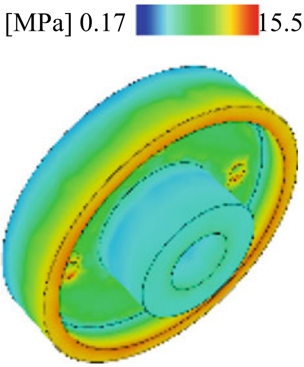


Fig. 6 Von Mises

3.2 Rigid Flanged Coupling

See Tables 6, 7, and 8.

3.2.1 Results

See Fig. 6.

3.3 Rigid Logged Coupling

Loads (Tables 9, 10, and 11).
Results (Fig. 7).

Table 9 Mesh

Type	Nodes	Elements
Solids	5948	3383

Table 10 Pressure1

Type	Pressure
Magnitude	4.8 MPa

Table 11 Pressure2

Type	Pressure
Magnitude	7.8 MPa

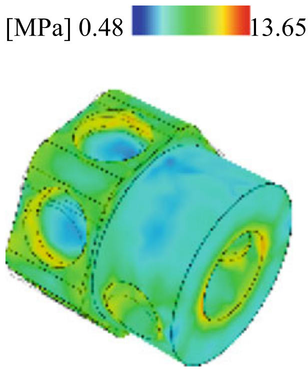


Fig. 7 Von Mises

4 Dimensions for Construction

4.1 Shaft

$$d = \sqrt[3]{\frac{16M}{\pi \tau}}$$

4.2 Flange

$$\begin{aligned} d_h &= 2d \\ l_h &= 1.5d \\ t &= d \end{aligned}$$

$$D_{\text{in}} = 2.5d$$
$$b_1 = 1.25d = \frac{D_{\text{in}}}{2}$$

4.3 Log

$$b * h = \frac{8M}{2.5 * d * \sqrt{3} * \tau}$$
$$l_l = 2d$$
$$b < b_1$$

h is the height of the log.

4.4 Pin

$$d_1 = \sqrt[3]{\frac{64 * M * l_b}{2.5 * \sqrt{3} * d * \pi * \sigma_b}}$$
$$d_1 = 4 * \sqrt{\frac{M}{\tau * \left(2.5 * d * \sqrt{3}\right) * \pi}}$$

4.5 Nut

$$d_{\text{inner}} = d_1$$
$$l_n = 0.8 * d_1$$

4.6 Connector Pin

$$\therefore d_2 = \sqrt{\frac{4M}{\pi * d * \tau}}$$

4.7 Protective Case

$$d_{p_c} = D_{\text{in}} * \frac{\sqrt[2]{3}}{2} + 2h + 10$$

4.8 Material Saved as Compared to Rigid Flanged Coupling

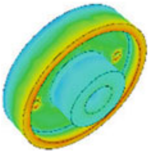
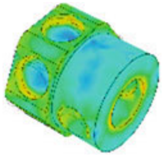
$$5.14488467d^3 - 6bhd - \frac{\pi}{8}Ndd_1 + 15\pi d_1^2$$

5 Conclusions

The following comparisons can be drawn by the analysis of the two couplings namely the rigid flanged and the rigid logged one (Table 12).

With respect to the results of simulations and derived equations, it can be stated that logged coupling gives a better performance with less material and stress concentration.

Table 12 Comparison

Serial No.	Rigid flange coupling	Basis	Rigid logged coupling
1.	 Maximum: 15.5 MPa	Stress	 Maximum: 13.65 MPa
2.	Excess material required to be built	Material	$5.14488467d^3 - 6bhd - \frac{\pi}{8}Ndd_1 + 15\pi d_1^2$ Volume material saved

Reference

1. Design of Machine elements by Bhandari