Computer Aided Design of Couplings

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Abstract

The research work explores computer-aided approach to the design of ten different couplings, viz a viz: flange, solid rigid, hollow rigid, old ham/ cross-sliding, pin type flexible, sleeve, seller cone/ compression, split muff, pulley flange and fairbian's lap-box couplings. The approach utilizes standard design equations of these couplings and link them together in computer software to determine the design parameters of the couplings. The work reviews the procedural steps involved in the design of couplings and the development of the software package using java as a tool for the design and dratfting of couplings. The design software named COUPLINGCAD combines with sketch template of a single process so as to generate the required parameters of the couplings. The COUPLINGCAD was tested with a number of case studies and the results obtained therein were quite satisfactory.

Keywords: Computer Aided design, Couplings, Couplingcad, Equations, Java

1: INTRODUCTION

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power [1]. Couplings do not normally allow disconnection of shafts during operation, though there do exist torque limiting couplings which can slip or disconnect when some torque limit is exceeded [2].

The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both [3]. Shaft couplings are used in machinery for protection against overloads and for power transmission. Most machines are integrated collection of power transmission elements that could be used for the business of moving energy or power from the place where it is generated to where it is to be used. Transmission element in machine tool could be mechanical, hydraulic, pneumatic or electric in nature. Shaft is one of the most important mechanical transmission element which needs to be coupled properly by the use of shaft couplings. A coupling is mainly to connect two shafts semi permanently.

Theoretically, the design and analysis of shaft couplings has been written extensively by several authors and the result put together in textbooks for use by the engineers.

SHAFTCAD software was developed through the research work on Computer-Aided design of power transmission shaft.The research establishedthe ease of designing power transmission shaft through various loadings [4].

A software package for the design of special transmission elements in which the various transmission elements such as brakes, power screws, chains and couplings were integrated into a unit package of which the package could only compute the design parameters without the detailed drawings of the machine components [5].

At present, there are no documented software developed for designing couplings except those one designed for spur gears, clutches, flywheel, rolling bearings, helical gears, power screws and chain drives as engineering transmission element [6],[7].

2 : EQUATIONS FOR DESIGN ANALYSIS

The various design equations needed for the design of these categories of couplings are as discussed below:

2.1 Design of Flange Coupling

For design purpose, it is to be noted that flange coupling transmit large torque. With reference to Figure 1 [8].
The following are the dimensional parameters to be considered when designing flange coupling; with lettering from figure 1

The appropriate number of bolts, i, is $$i = 0.2d + 3 \quad (1)$$

Where d = shaft diameter

The average value of the diameter of the bolt circle, D_1 in cm

$$D_1 = 2d + 5 \quad (2)$$

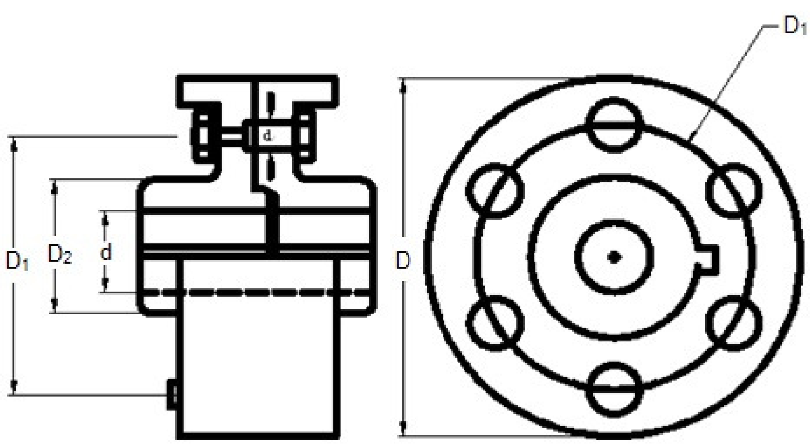

FIGURE 1: Flange coupling.

The hub diameter, D_2, is $$D_2 = 1.5d + 2.5cm \quad (3)$$

The outside diameter of flange, D, is $$D = 2.5d + 7.5cm \quad (4)$$

The hub length, L, is $$L = 1.25d + 1.875 \quad (5)$$

The power *N* is in kilowatt, is $$N = \frac{d^3 \Pi n \xi \tau_s}{1558400} \text{ N} \quad (6)$$

Where n = speed (r.p.m), τ_s = design shear stress in shaft and

ξ = factor which takes care of the reduced strength due to keyway.

And $$\zeta = 1 + \frac{0.2x + 1.1y}{d}$$

Where: x = width of keyway, cm and y = depth of keyway, cm

The torque transmitted by the coupling, M_{tc}, is $$M_{tc} = \frac{97400}{N} \quad (7)$$

Where N = Power in Kilowatt

Torque transmitted through bolts, M_{tb}, $$M_{tb} = i\left(\frac{\Pi d_1^{\ 2}}{4}\right)\tau_b \frac{D_1}{2} \quad (8)$$

Torque capacity based on shear of flange, M_{tsf},

$$M_{tsf} = t(\pi D_2)\tau_f \frac{D_2}{2} \quad (9)$$

where τ_f is the shear stress in flange at the outside hub diameter, kg.

The mean radius, r_m, $$r_m = \left(\frac{D + d}{2}\right)cm \quad (10)$$

The tension of load in each bolt, $$F_b = \frac{M_{tc}}{i \mu r_m} \quad (11)$$

The preliminary bolt diameter, d_1 , is $$d_1 = \frac{0.5d}{\sqrt{i}} \quad (12)$$

The allowable or design stress in bolts, τ_b $$\tau_b = \frac{779200N}{\pi d_1^{\ 2} i n D_1} \quad (13)$$

Flange thickness, $$t = 0.25d \quad (14)$$

Design shear stress, $$\tau_f = \frac{2M_{tc}}{\pi D_1^{\,2} t} \tag{15}$$

2.2 Design of Solid Rigid Coupling

Refer figure 2 [8]

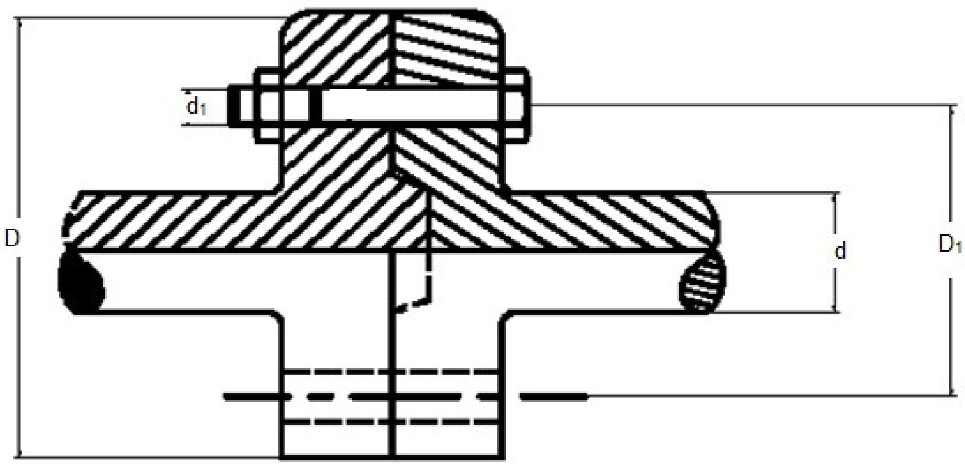

FIGURE 2: Solid rigid coupling

The parameters for design purposes are:

The number of bolts, i, is $$i = \frac{1}{3}d + 5 \tag{16}$$

Flange thickness t, is $$t = (0.25d \text{ to } 0.28d) \tag{17}$$

The diameter of bolt circle, D_1, is $$D_1 = (1.4d \text{ to } 1.6d) \tag{18}$$

The outside diameter of flange D, is $$D = D_1 + (2d \text{ to } 3d) \tag{19}$$

The diameter of bolt, d_1, is $$d_1 = \sqrt{\frac{\zeta d^3 \tau_s}{2iD_1\tau_b}} \tag{20}$$

2.3 Design of Hollow Rigid Coupling

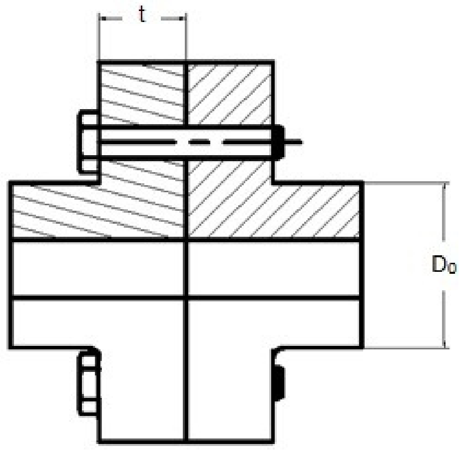

FIGURE 3: Hollow rigid coupling

The parameters for consideration as shown in figure 3 above [8] are as follows:

The outside diameter of Hollow rigid, D_0, is expressed as

$$D_o = 2.5d + 7.5cm \tag{21}$$

Minimum number of bolts, i, $$i = \frac{D_o}{2} \tag{22}$$

The diameter of bolt circles, D_1, $$D_1 = 1.4D_o \tag{23}$$

The mean diameterw of bolt, d_1 is $$d_1 = \sqrt{\frac{(1-k^4)D_o{}^3\tau_s}{2iD_1\tau_b}} \tag{24}$$

Where $$k = \frac{d}{D_o}$$

2.4 Design of Oldham Coupling

The length of the boss, L, is $$L = 1.75dcm \tag{25}$$

The diameter of the boss, D_2, is $$D_2 = 2d \tag{26}$$

The thickness of flange, t,, is $$t = 0.75d \tag{27}$$

Also diameter of Disc, D, is $$D = 3L \tag{28}$$

Distance between centre lines of shafts in Oldham's, a,

$$a = D - 3d) \tag{29}$$

Breadth of groove, W, is $$\mathrm{W} = D/6 \quad (30)$$

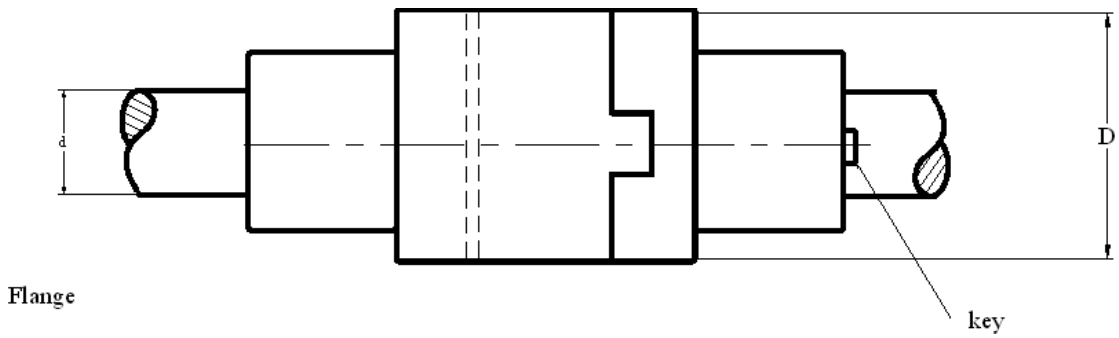

FIGURE 4: Oldham coupling

The thickness of the groove, h_1, is $$h_1 = \frac{W}{2} \quad (31)$$

The thickness of central disc, h, is $$h = \frac{W}{2} \quad (32)$$

The total pressure on each side of the coupling, F,

$$F = 1/4\, pDh \quad (33)$$

Where $p \neq 85 kgf/cm^2$

The torque transmitted on each side of the coupling, M_{tc}

$$M_{tc} = 2Fh \text{ or } M_{tc} = pD^2h/6 \quad (34)$$

Power transmitted, N, is $$N = \frac{PD^2hn}{430000} \text{ hp} \quad (35)$$

$$N = 1.734 * 10^{-3} PD^2hn \text{ W}$$

Where n = speed in (r.p.m)

2.5 Design of Pin Type Flexible Coupling

With reference to figure 5 and its lettering [8] the below formular are derived.

The outside diameter, D, is $$D = 4d \quad (36)$$

The clearance, b, $$b = 0.1d \quad (37)$$

The hub diameter, D_2 is $$D_2 = 2d \quad (38)$$

The hub length, L, is $$L = 1.75d \quad (39)$$

Diameter of pin at the rock, d_1 $$d_1 = d_p cm \quad (40)$$

$$i = 0.2d + 3 \quad (41)$$

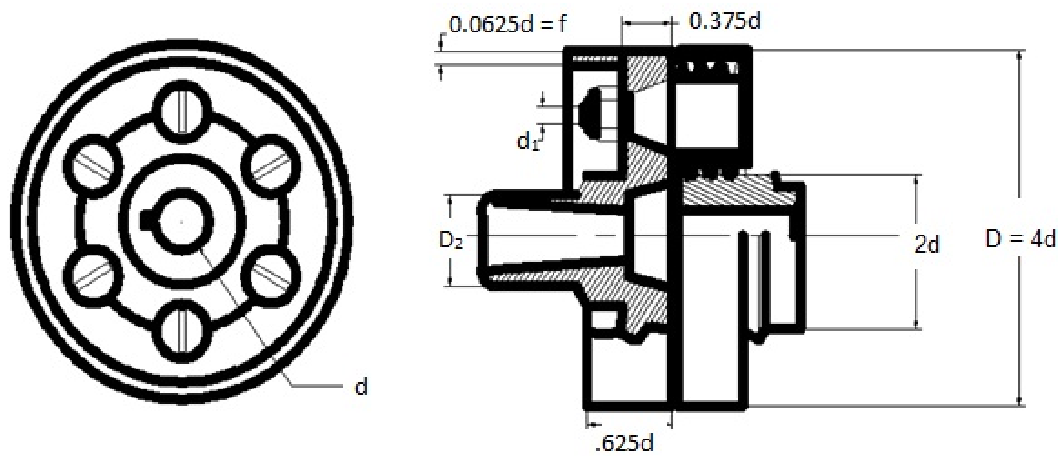

FIGURE 5: Pin type flexible coupling

Force at each Pin, *F*, is defined as $$F = 0.785 d_p^{\,2} \tau_p \quad (42)$$

Where τ_p = shear stress in pin = allowable shearing stress kgf/cm^2

Bending stress in Pin, σ_b $$\sigma_b = F \frac{\left(l/2 + b \right)}{\pi/32 \, d_p^{\,3}} \quad (43)$$

The bearing pressure, $P_b \, kgf/cm^2$, is $$P_b = \frac{F}{Ld^1} \quad (44)$$

Where d_1= outside diameter of the bush and

$$d = d_2 + 0.115 d_1 + t$$

Where d_2 = diameter of hole for bolt, cm.

The torque transmitted, M_{tc}, is $$M_{tc} = \frac{iFD_1}{2} \quad (45)$$

2.6 Sleeve Coupling

With reference to figure 6 and its lettering [8] the below formular are derived:

The outside diameter of sleeve, $D = 2d + 1.3cm$ (46)

The length of the sleeve, L, is $L = 3.5d$ (47)

The length of the key, l, is $l = 3.5d$ (48)

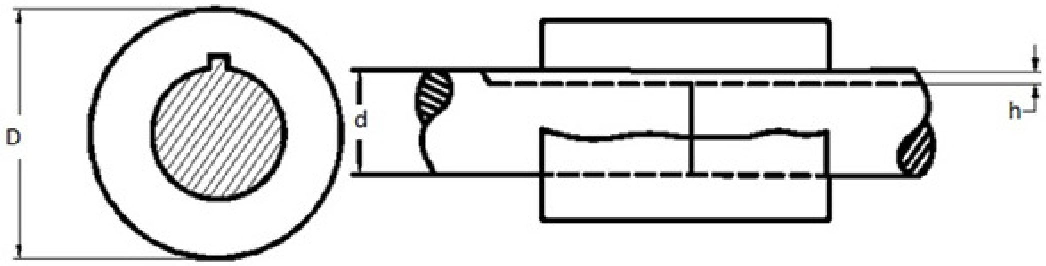

FIGURE 6: Sleeve coupling

The torque transmitted, M_{tc} $M_{tc} = \frac{\pi\zeta\tau_d d^2}{144}$ (49)

The width of keyway, b, $b = \frac{2M_{tc}}{\tau_{d_2} ld}$ (50)

Where τ_{d_2} = design shear stress in key

The thickness of key, h, is $h = \frac{2M_{tc}}{\sigma l_b^1 ld}$ (51)

Where $\sigma^1{}_b$ = design bearing stress for keys

2.7 Seller Cone Coupling

The length of the box L, is $L = \frac{3.65d + 4d}{2}$ (52)

The outside diameter of the conical sleeve, D_1

$$D_1 = \left(\frac{1.875d + 4d}{2}\right) + 1.25cm \quad (53)$$

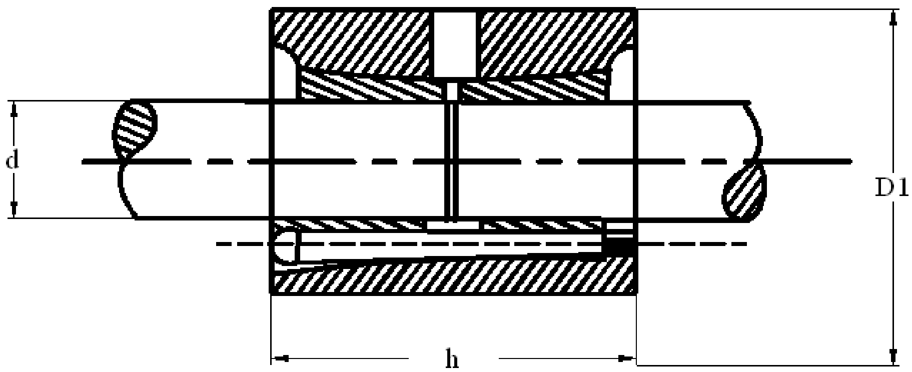

FIGURE 7: Seller cone coupling

The outside diameter of the box D_2 $$D_2 = 3d \quad (54)$$

The length of the conical sleeve, L, is $$L = 1.5d \quad (55)$$

2.8 Design of Split Muff Coupling

Refer Figure 8 [8]

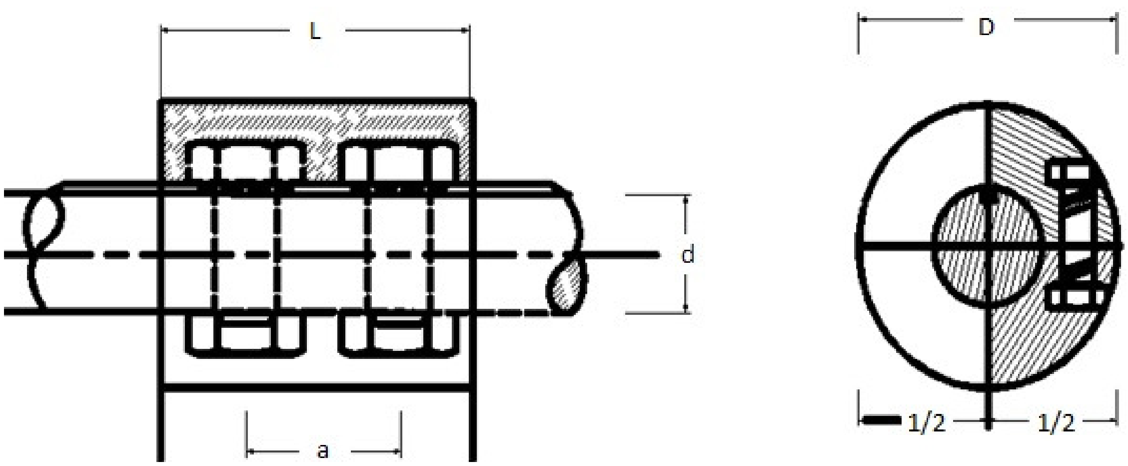

FIGURE 8: Split Muff coupling

The outside diameter of the sleeve, D, is $$D = 2d + 1.3cm \quad (56)$$

The length of the sleeve, L, $$L = (3.5d \ \ or \ \ 2.5d) + 5cm \quad (57)$$

The torque transmitted, M_{tc}, $$M_{tc} = \frac{\pi^2 d_c{}^2 \sigma_t \mu i d}{16} \quad (58)$$

Where d_c = core diameter of the clamping bolts, cm and i = number of bolts

2.8 Design of Pulley Flange Coupling Refer Figure. 9

The parameters for consideration are;

The number of bolts, i, is $$i = 0.2d + 3 \quad (59)$$

Bolt diameter d_1 is, $$d_1 = \frac{0.5d}{\sqrt{i}} \quad (60)$$

The width of flange, l_1 $$l_1 = 0.5d + 2.5cm \quad (61)$$

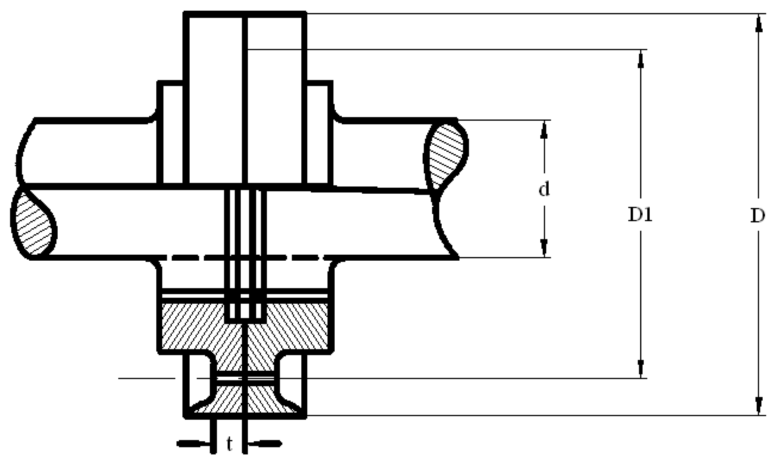

FIGURE 9: Pulley flange coupling

The thickness of the flange, t $$t = 0.25d + 0.7cm \quad (62)$$

The hubs length, l, is $$l = 1.4d + 1.75cm \quad (63)$$

The hub diameter, D_2 is, $$D_2 = 1.8d + 1cm \quad (64)$$

The average value of the diameter of the bolt circle, D_1,

$$D_1 = 2d + 2.5cm \quad (65)$$

The outside diameter of flange, D_f $$D_f = 2.5d + 7.5cm \quad (66)$$

2.10 Design of Fairbain's Lap-Box Coupling

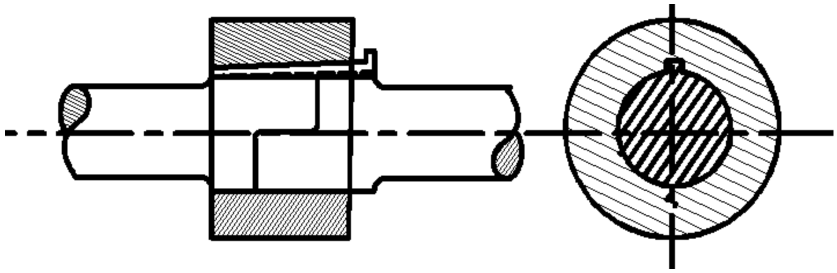

FIGURE 10: Fairbain's lap-box coupling

The outside diameter of sleeve, D, is $D = 2d + 1.3cm$ (67)

Length of lap, l, $l = (0.9d + 0.3)cm$ (68)

The length of sleeve L, is $L = 2.25d + 2c$ (69)

3.0 METHODOLOGY

Using the above design equations and procedures, a CAD System/Software for determining necessary coupling parameters and generating automatic drawings of the shaft for a particular application was developed. The design sequence shown in figure 11 was adopted for easier programming. The software was developed with JAVA programming language, which is users' friendly and readily compatible with Microsoft Windows environment. The development of COUPLINGCAD involves; creating the user interface, setting object properties and writing of codes. And these were later tested to see if the design codes give the right result.

If COULINGCAD is installed on any computer system, when it is clicked to be used, the opening screen features that can be seen is shown in figure 12. As the next button on the opening environment is clicked, this bring out the various couplings (see figure 13) which will give room for users to be able to select the intended type to be considered for any given engineering design problems. For example, if flange coupling is clicked, this takes the user to the design environment as shown in Figure 14.

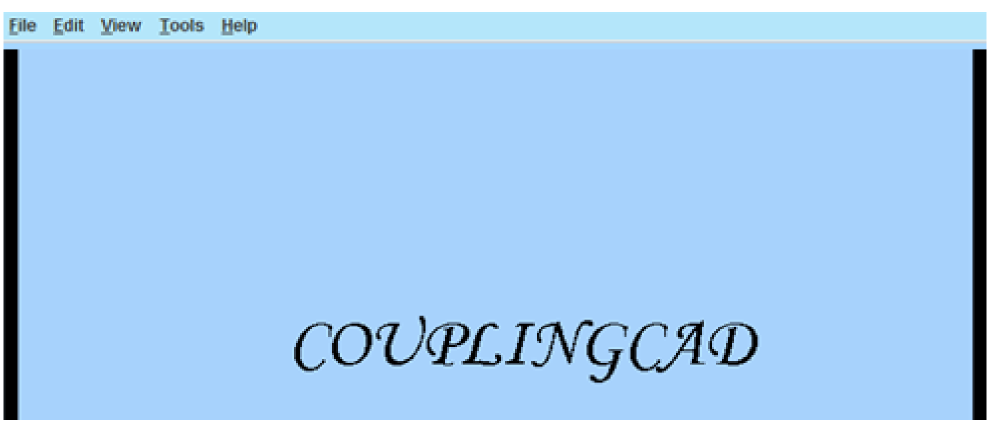

FIGURE 12 : COUPLINGCAD Main Entry Screen

FIGURE 13: COUPLINGCAD Main Menu Globe

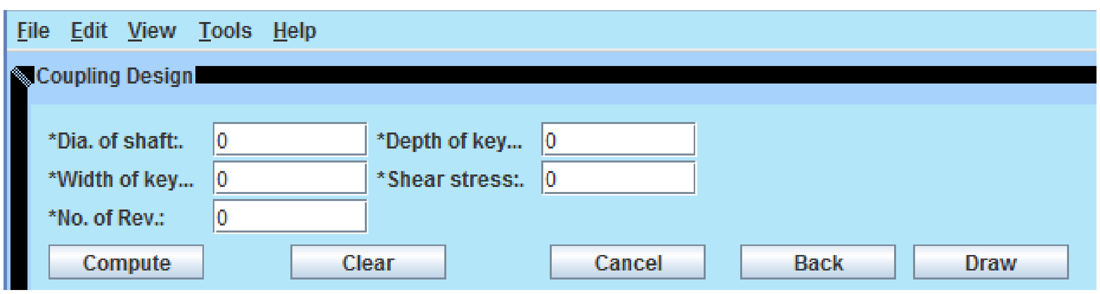

FIGURE 14: COUPLINGCAD Main Dimension Menu

4.0 RESULTS AND DISCUSSION

Case studies of samples problems from standard text materials were considered to test or validate the software and by comparing the results got with manually generated solution. Few of these examples are presented below:

4.1 Case Study I

Design a flange coupling to connect two shafts each of 55cm diameter transmitting at 350 r.p.m. with allowable shear stress of 40N/cm^2. The width and depth of the keyway is 18cm and 6cm respectively.

Solution: These values are being input into the package as seen in figure 15. The result is as shown in figure 16

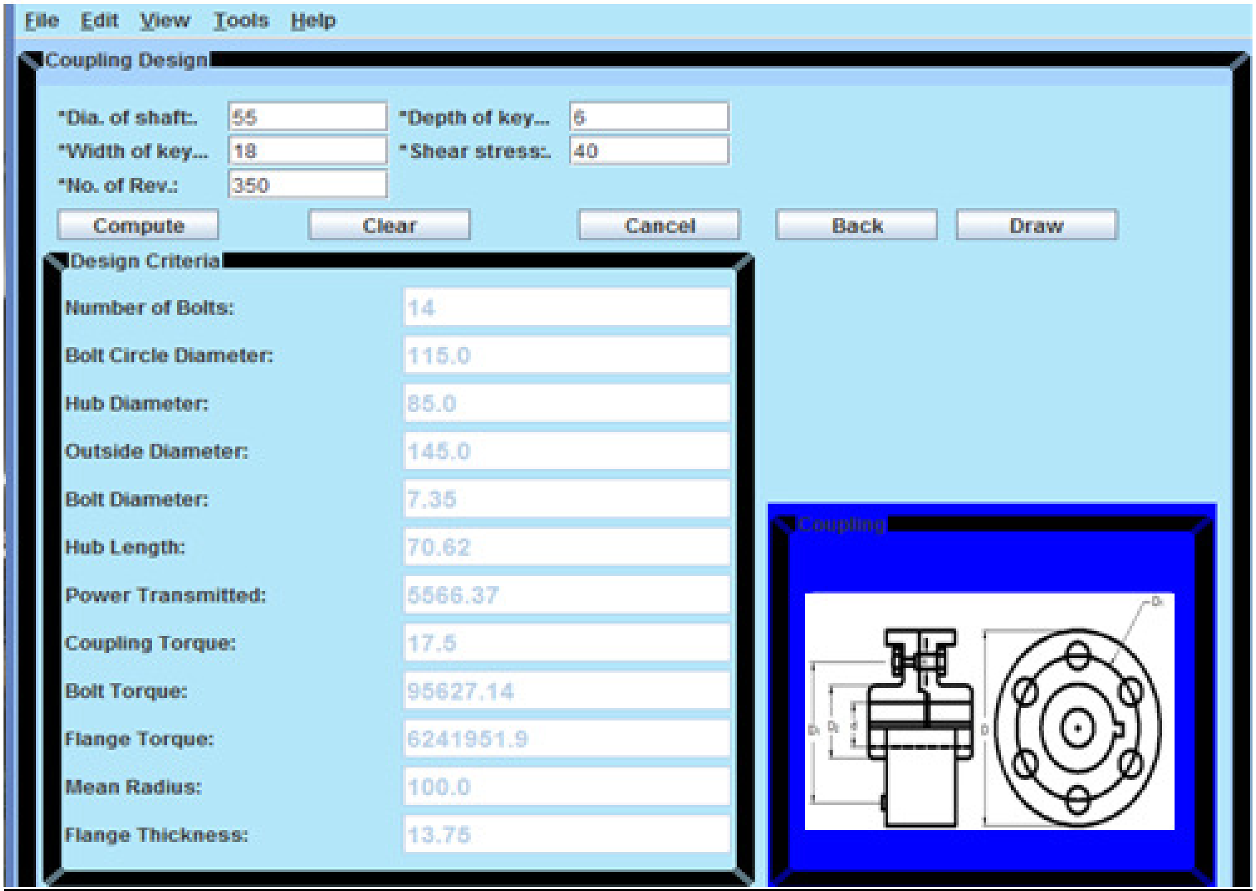

FIGURE 15: Snapshot showing the input parameters for flange coupling

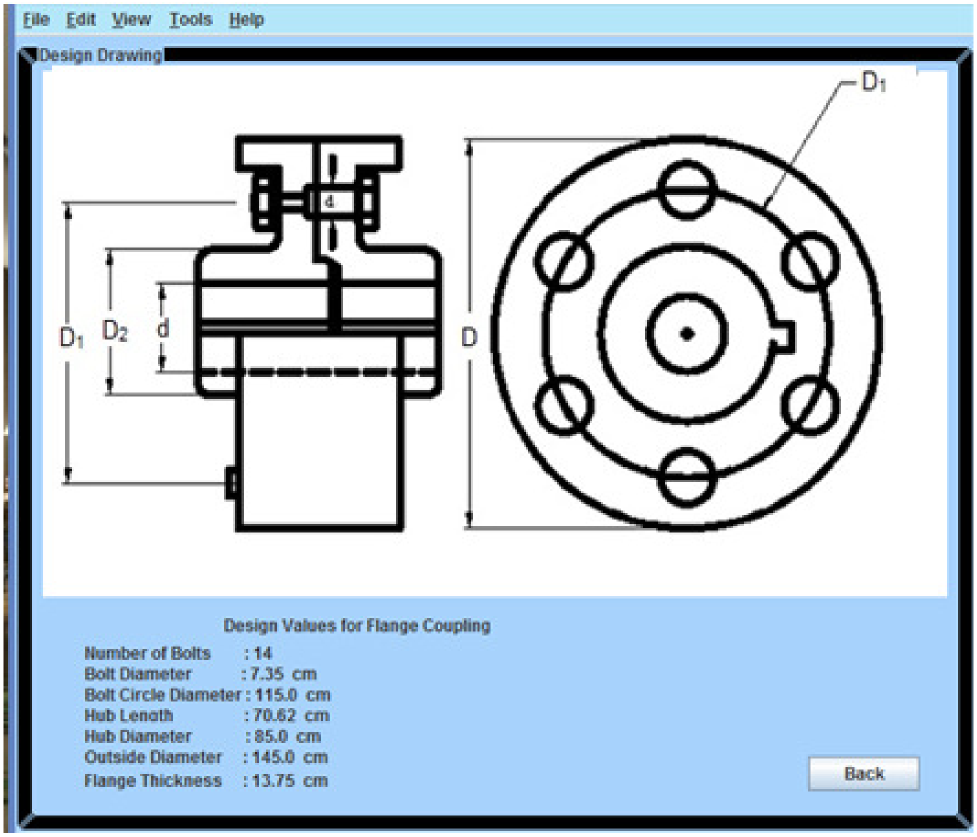

FIGURE 16: Snapshot showing output parameters design values for flange coupling

<u>Manually Solved Solution to Case Study I</u>

Given parameters are:

Diameter, d= 55cm, allowable stress in shaft, τ_s = 40N/cm^2, Speed, n= 350 r.p.m, Width of keyway, x= 18, Depth of keyway, y= 6cm.

Using the designed equations spelt above, the following parameters were calculated for.

Appropriate number of bolts needed, $I = 0.2d + 3 = 0.2 \times 55 + 3 = 14 bolts$

Bolt circle diameter, $D_1 = 2d + 5 = 2 \times 55 + 5 = 115cm$

The hub diameter, $D_2 = 1.5d + 2.5cm = 1.5 \times 55 + 2.5 = 85cm$

Outside diameter of flange, $D = 2.5d + 7.5 = 2.5 \times 55 + 7.5 = 145cm$

Hub length, $L = 1.25d + 1.875 = 1.25 \times 55 + 1.875 = 70.62cm$

Power transmitted, $N = \dfrac{d^3 \Pi n \xi \tau_s}{1558400}$,

But, ξ = factor which takes care of the reduced strength due to keyway.

$$\zeta = 1 + \frac{0.2x + 1.1y}{d} = 1 + \frac{0.2 \times 18 + 1.1 \times 6}{55} = 1.185$$

$$N = \frac{55^3 \times \Pi \times 350 \times 1.185 \times 40}{1558400} = 5566.37$$

The torque transmitted by the coupling, M_{tc}

$$M_{tc} = \frac{97400}{n} N = \frac{97400 \times 55566.37}{350} = 17.5Ncm$$

Bolt diameter, $d_1 = \frac{0.5d}{\sqrt{i}} = \frac{0.5 \times 55}{\sqrt{14}} = 7.35$

Bolt torque, $M_{tb} = i\left(\frac{\Pi d_1^{\ 2}}{4}\right)\tau_b \frac{D_1}{2}$

The allowable or design stress in bolts, $\tau_b = \frac{779200N}{\pi d_1^{\ 2} inD_1}$

$$\tau_b = \frac{779200 \times 5566.37}{\pi \times 7.33^2 \times 14 \times 350 \times 115} = 45\, N/cm^2$$

$$\therefore M_{tb} = 14\left(\frac{\Pi \times 7.33^2}{4}\right) \times 45 \times \frac{115}{2} = 95627.14Ncm$$

Flange torque, $M_{tsf} = t(\pi D_2)\tau_f \frac{D_2}{2}$

Flange thickness, $t = 0.25d = 0.25 \times 55 = 13.75cm$

Design shear stress, $\tau_f = \frac{2M_{tc}}{\pi D_1^{\ 2} t}$

$$\tau_f = \frac{2 \times 17.5}{\pi \times 115^2 \times 13.75} = 61\, N/m^2$$

$$M_{tsf} = 13.75(\pi \times 85)61 \times \frac{85}{2} = 6241951.9Ncm$$

The mean radius, $r_m = \left(\frac{D + d}{2}\right)cm = \frac{145 + 55}{2}cm = 100cm$

4.2 Case Study II

Design a split muff coupling to join two shafts of diameter 35cm, rotating at a speed of 400 r.p.m. and has shear stress of 50N/cm^2. The keyway's width and depth are 16cm and 4cm respectively.

Solution:These values are being input into the package as seen in figure 17. The result is as well shown in figure 18.

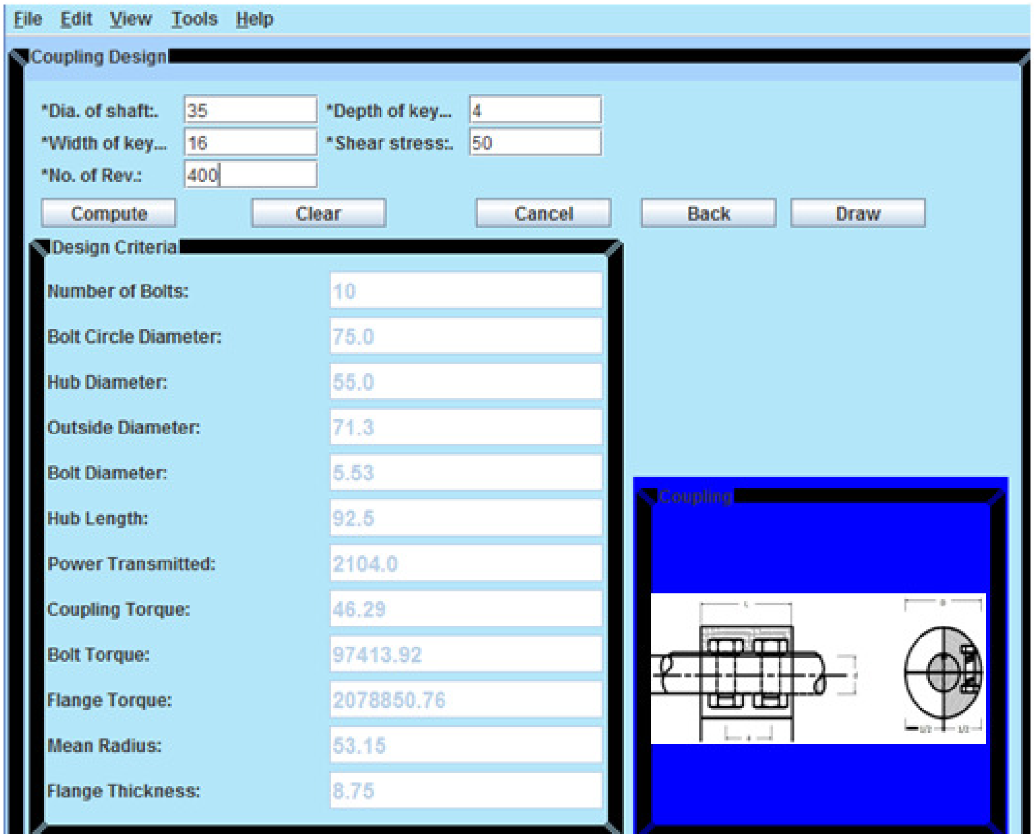

FIGURE 17: Snapshot showing the input parameters for split-muff coupling

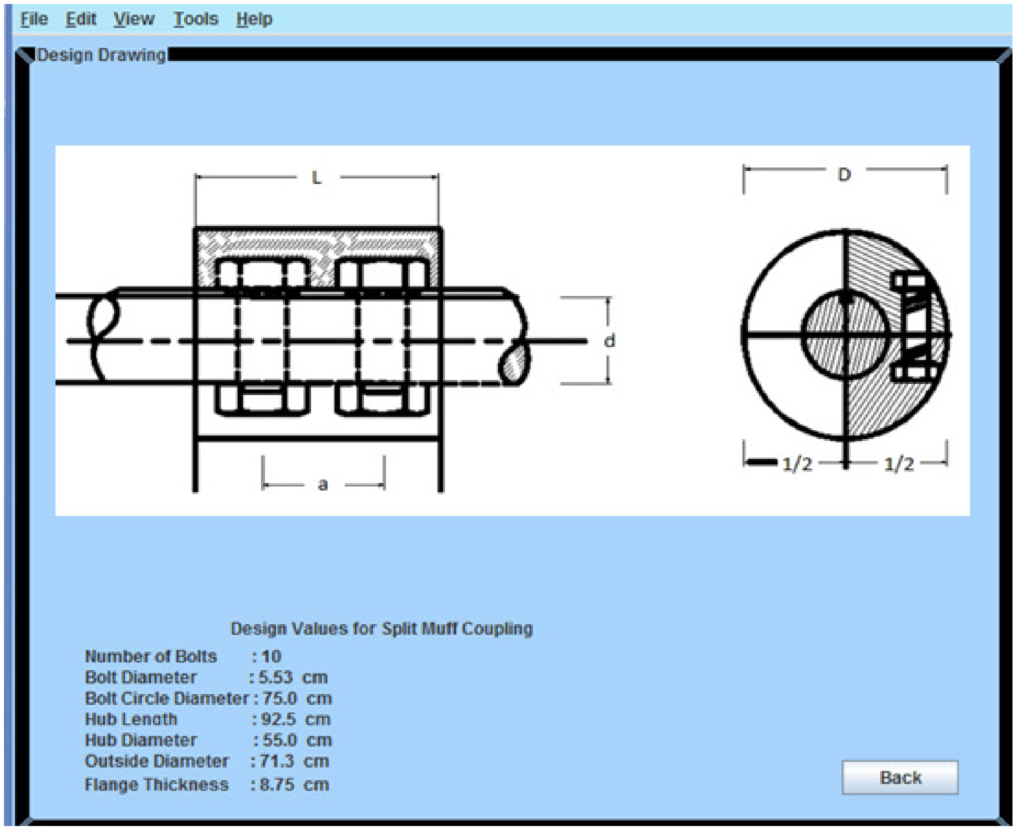

FIGURE18: Snapshot showing output parameters design values for split-muff coupling

Manually Solved Solution to Case Study II

Given parameters are:

Shaft diameter, d=35cm, allowable stress in shaft, τ_s=50N/cm^2, speed, n= 400 r.p.m., width of keyway, x= 16cm, depth of keyway, y= 4cm.

Using the designed equations spelt above, the following parameters were calculated for:

Appropriate number of bolts needed, $I = 0.2d + 3 = 0.2 \times 35 + 3 = 10 bolts$

Bolt circle diameter, $D_1 = 2d + 5 = 2 \times 35 + 5 = 75cm$

The sleeve diameter, $D_2 = 1.5d + 2.5cm = 1.5 \times 35 + 2.5 = 55cm$

Outside diameter of sleeve, $D = 2d + 1.3cm = 2 \times 35 + 1.3cm = 71.3cm$

Sleeve length, $L = 2.5d + 5cm = 2.5 \times 35 + 5 = 92.5cm$

Power transmitted, $N = \dfrac{d^3 \Pi n \xi \tau_s}{1558400}$

ξ = factor which takes care of the reduced strength due to keyway.

$$\zeta = 1 + \frac{0.2 \times 16 + 1.1 \times 4}{35} = 1.217$$

$$N = \frac{35^3 \times \Pi \times 400 \times 1.217 \times 50}{1558400} = 2104 Kw$$

The torque transmitted by the coupling, M_{tc}

$$M_{tc} = \frac{\pi^2 d_c^{\,2} \sigma_t \mu i d}{16} = \frac{\pi^2 \times d_c^{\,2} \times \sigma_t \times \mu \times 10 \times 35}{16} = 46.29 Ncm$$

Bolt diameter, $d_1 = \frac{0.5d}{\sqrt{i}} = \frac{0.5 \times 35}{\sqrt{10}} = 5.53cm$

Bolt torque, $M_{tb} = i\left(\frac{\Pi d_1^{\,2}}{4}\right)\tau_b \frac{D_1}{2}$

But, the allowable or design stress in bolts, is

$$\tau_b = \frac{779200N}{\pi d_1^{\,2} i n D_1} = \frac{779200 \times 2104}{\pi \times 5.53^2 \times 10 \times 400 \times 75} = 57\, N/cm^2$$

$$M_{tb} = 10\left(\frac{\Pi \times 5.53^2}{4}\right) \times 57 \times \frac{75}{2} = 97413.92$$

Sleeve torque, $M_{tsf} = t(\pi D_2)\tau_f \frac{D_2}{2}$

Sleeve thickness, $t = 0.25d = 0.25 \times 35 = 8.75cm$

Design shear stress, $\tau_f = \frac{2M_{tc}}{\pi D_1^{\,2} t} = \frac{2 \times 46.29}{\pi \times 75^2 \times 8.75} = 60\, N/cm^2$

$$M_{tsf} = 8.75(\pi \times 55)60 \times \frac{55}{2} = 2078850.76 Ncm$$

The mean radius, $r_m = \left(\frac{D+d}{2}\right)cm = \frac{71.3 + 35}{2}cm = 53.15cm$

4.3 Comparative View of the Results for Case Study I and Case Study II

The means to excellently validate the package developed is to compare the results obtained.

From table 1 shown, comparatively, the results got when manually solved or calculated for is same as the results got using the COUPLINGCAD for the various designed parameters for both case study I and case study II. This implies that the COUPLINGCAD is excellently packaged.

Case Study I				Case Study II		
Design Parameters	**COUPLING CAD Result**	**Manually Solved Result**		**Design Parameters**	**COUPLING CAD Result**	**Manually Solved Result**
Number of bolts	14	14		Number of bolts	10	10
Bolt circle diameter	115.0cm	115.0cm		Bolt circle diameter	75.0cm	75.0cm
Hub diameter	85.0cm	85.0cm		Sleeve diameter	55.0cm	55.0cm
Outside diameter	145.0cm	145.0cm		Outside diameter	71.3cm	71.3cm
Bolt diameter	7.35cm	7.35cm		Bolt diameter	5.53cm	5.53cm
Hub length	70.62cm	70.62cm		Sleeve length	92.5cm	92.5cm
Power	5566.37Kw	5566.37Kw		Power	2104.0Kw	2104.0Kw
Coupling torque	17.5	17.5		Coupling torque	46.29Ncm	46.29Ncm
Bolt torque	95627.14	95627.14		Bolt torque	97413.92	97413.92
Flange torque	6241951.9	6241951.9		Sleeve torque	2078850.76	2078850.76
Mean radius	100cm	100cm		Mean radius	53.15cm	53.15cm
Flange thickness	13.75cm	13.75cm		Sleeve thickness	8.75cm	8.75cm

TABLE 1: Tabulated results of designed parameters using the COUPLINGCAD and manually solved approach for both Case study I and II

5.0 CONCLUSION

The case studies considered proved that the COUPLINGCAD is excellently packaged and it could be used in solving problems related to the various couplings of choice as discussed. The COUPLINGCAD is quite accurate with high precision. It is noticed that with it, time management is ensured as calculations are done within a short time which is not so with the manually solved approach.

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