AN INTEGRATED APPROACH TO DESIGN AND ANALYZE UNPROTECTED TYPE FLANGE COUPLING[+]

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Abstract

Most of mechanical CAD software provides mechanical drafting and design, which involves a variety of different types of drawings. All these drawings require coordinate–geometric data and descriptive data. The objective of this work is to establish software programs for designing, visualizing and analyzing of unprotected type flange coupling as a mechanical element of wide range of applications.

The approach includes: (a) Data base of some carbon and alloy steel (used in manufacturing of flanges) with some of their corresponding mechanical properties, (b) Software program for the generation of geometric data of the flange coupling components (flange, hub, bolts and key set), (c) Data exchange file (DXF) for converting the calculated geometric data to a well known AutoCAD system for the purpose of visualization, (d) Model analysis by finite element method using MATLAB programming system to show the robust and weakness regions, and (e) A graphical user interface (GUI) to versatile and elegance the process.

المستخلص

معظم برامج التصميم المعان بالحاسوب للاجزاء الميكانيكية توفر امكانية رسم وتصميم هذه الاجزاء، حيث تتضمن هذه البرامج انواع مختلفة ومتنوعة من الرسومات. وكل هذه الرسومات تتطلب احداثيات للبيانات الهندسية بالاضافة الى البيانات الوصفية. الغرض من هذا البحث هو تأسيس برامج حاسوبية لتصميم وعرض وتحليل قارنة (flange coupling) غير محمية كأحد الاجزاء الميكانيكية المهمة الواسعة الاستخدام.

يتضمن البحث: (أ) قاعدة بيانات لبعض الانواع من الفولاذ الكاربوني والفولاذ السبائكي المستخدم في تصنيع القارنات بالاضافة الى بعض المواصفات الميكانيكية لهذه الانواع. (ب) برامج حاسوبية لتوليد البيانات الهندسية لمكونات القارنة مثل (الحافة flange ، المحور hub ، اللوالب bolts ومجموعة الخابور key-set). (جـ) برنامج لتوليد ملف تبادل البيانات (DXF) وتحويل البيانات التصميمية الى حزمة الرسم AutoCAD لغرض عرضها. (د) برنامج حاسوبي لتحليل التصميم باستخدام طريقة العناصر المحددة بأستخدام البرنامج الهندسي MATLAB. (هـ) واجهة التطبيق التفاعلية (GUI) بين المستخدم والبرنامج لتسهيل وتنظيم عملية التصميم والتحليل والعرض.

Keywords: *CAE, CAD, DXF, Mechanical design and FEM.*

Nomenclature

T	**Delivered torque**	τ_{sp}	Permissible shear stress of shaft material
P	Transmitted power	τ_{sI}	Induced shear stress of shaft material
ω	Angular velocity [$\omega=2\pi N/60$]	τ_b	Permissible shear stress of bolt material
N	Rotational speed	τ_{kp}	Permissible shear stress of key material
D	Hub diameter	σ_{cbp}	Permissible Crushing stress of bolt material
t	Thickness of flange	σ_{ckp}	Permissible Crushing stress of key

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D_1 Pitch circle diameter
D_2 Outer diameter of flange
d Shaft diameter
n_b Number of bolts
d_b Bolt diameter
k Constant [k=d/D]
τ_{fp} Permissible shear stress of flange material
τ_{fI} Induced shear stress of flange material

material
L Length of key
L_h Length of hub
F Applied couple
E Modules of elasticity
Y Poisson's ratio
γ_{fI} Shear strain in x-y plane
r_f Fillet radius
w_b Width of key

Introduction

Couplings are basically shaft connectors that do not allow slipping between two connected shafts. Couplings can be generally grouped into two classes: rigid couplings: clamps two shafts together and flexible couplings: shaft misalignment requires flexible couplings instead of rigid couplings [1].

CAD systems were developed from simple graphic editors (with limited drawing capabilities) to be powerful systems that hold millions of standard part stored inside them with influent abolition to analyze, find design errors and identify weak points, in addition to powerful physical and analytical simulations that give exact solutions and accurate predictions.

CAD software packages witnessed rapid growth and development. AutoCAD release 2.5, which was produced in 1982 for IBM compatible personal computers and Dos platforms, for example, began as a simple program with limited commands (up to 150), basic 2D ability.

Nowadays mechanical desktop (MDT) release 5 from the same company (AutoDesk), which was produced in 2000 for windows platform and Pentium IV computer, is a very advanced program that holds inside it more than 1.2 million 2D and 3D predrawing [2].

There are many researches concerned with coupling design and CAD systems, Citarella and Gerbino [3] develop a CAD/CAE methodology for coupling design, oriented to an efficient integration between CAD systems and boundary element solvers, this methodology is based on a synergetic, and strictly integrated usage of the pro/ENGINEER CAD system, for geometric model generation, and researches use IGES as a CAD data transfer in their work. While Hussam and others [4] were building an automatic dimensioning procedure by creating a DXF format. The initial drawing and its dimensions are displayed automatically on AutoCAD package window at one time, and Baraa and others [5] use DXF file and AutoCAD package to allocate the reference positions on mold dies blocks automatically, so the AutoCAD is used as a input\output interface.

In real world all of commercial CAD systems provide on of the following tasks [6]:

- Geometric modeling
- Bills of materials
- Arithmetical calculations
- Model analysis

We know that none of the existing commercial CAD system performs two or more of the above tasks. This work is dedicated to built a software program which includes all the mathematical design considerations for flange coupling. This software program generates the geometric design data and converts them to a well developed AutoCAD package through out a translator software program.

The objective of translator software program is to translate the generated geometric design data into real graphics of intended object on the AutoCAD interface as a final drawing. After that, the final design step is to analyze the product using finite element analysis in order to modify some of the product dimensions according to the results of analysis. Figure (1) shows a schematic representation of the proposed system.

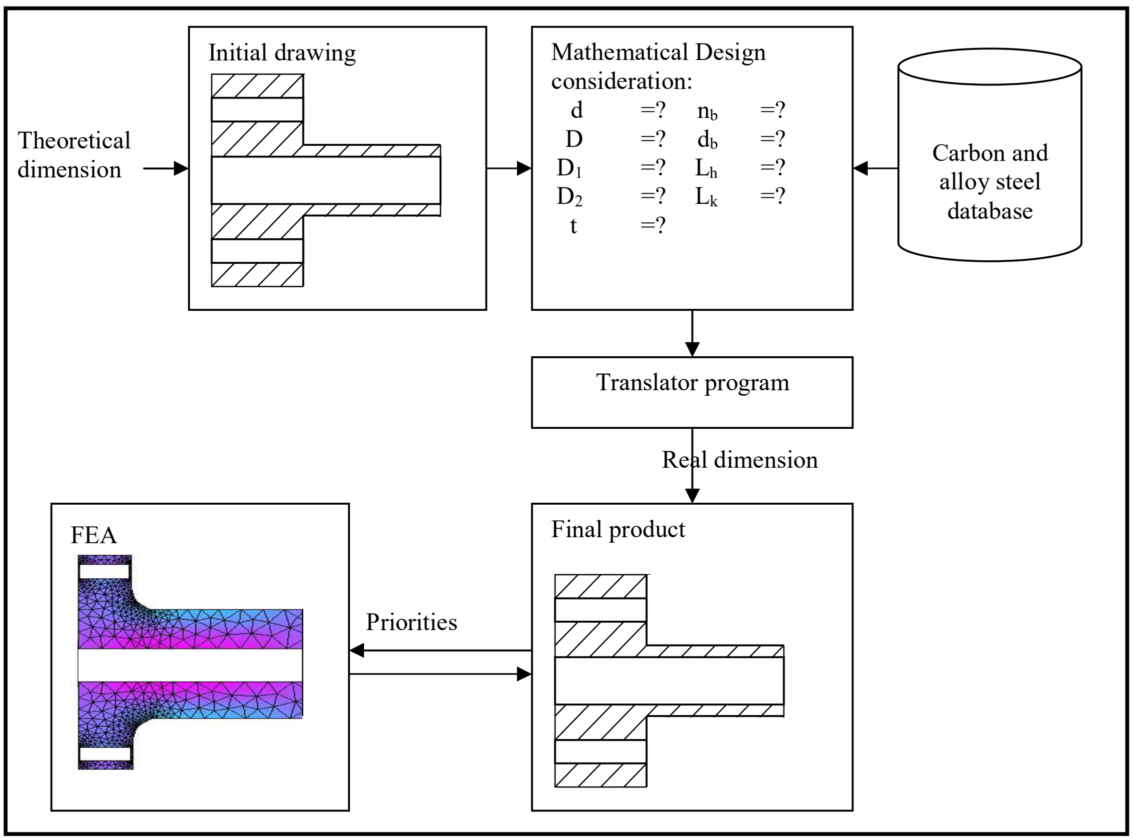


Fig. (1) : Schematic representation of the proposed system

Mathematical Design Considerations

This section deals with the construction of a software program for the calculation of the geometric design data based on a specific mathematical formula (most of them are not new) for flange coupling components.

The inputs to this program are:

- The delivered torque
  If the torque is unknown, the user can input the transmitted power and rotational speed, in this case the system will automatically evaluate the required torque using [7]:
  $T = P/\omega$ ………………… *(1)*

- The type of material for each component of flange coupling set. The system provides a list of some carbon and alloy steel materials used in the manufacturing of flange coupling components. The user can easily select any suitable material, at this point the system will automatically acquire the mechanical properties of selected metal.

Figure (2) shows the form of the user interface for the input system.

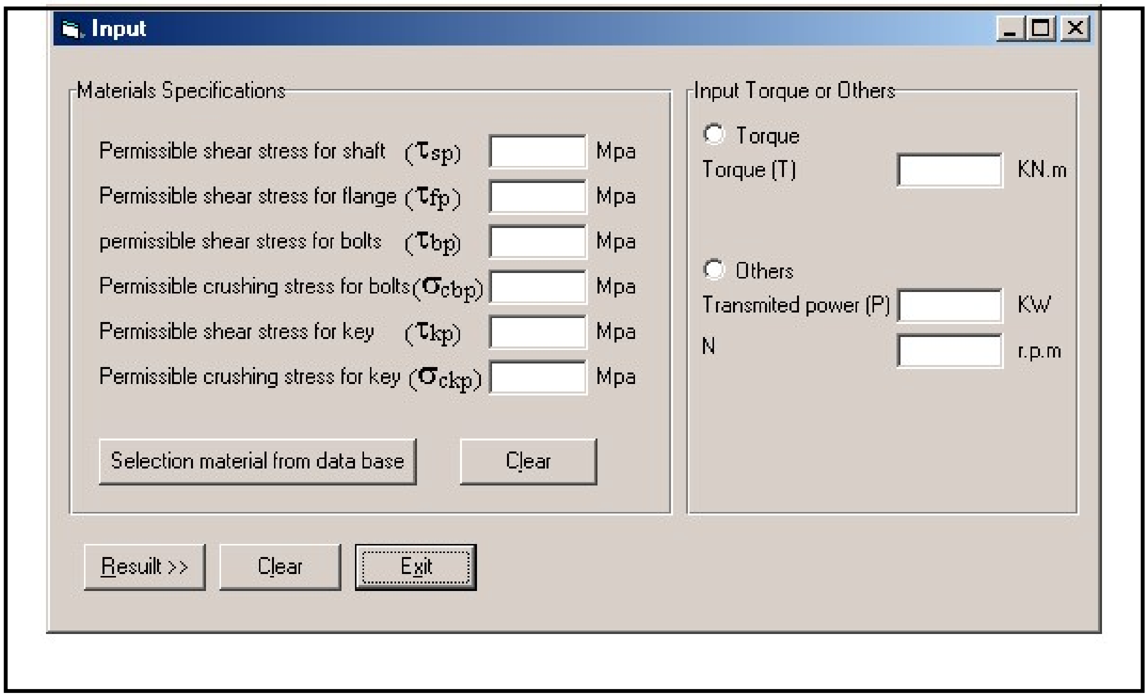


Fig. (2): user interface form of the input system

The output of this program is the real dimensions of all the flange components. The calculation of these dimensions is based on the following mechanical standard [7] see Figure (3).

$D \;\; = 2d$
$t \;\;\; = 0.5\, d$
$D_1 = 3d$
$D_2 = 4d$

Table 1 shows the number of required bolts according to the shaft size [7] :

Table (1) : number of bolts corresponding to shaft size

Shaft size	Up to 40 mm	Up to 100 mm	Up to 180 mm
n_b	3	4	6

Where the shaft diameter can be calculate from [7]:

$$d = \left(\frac{16T}{\pi \tau_{sp}} \right)^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Generally, the calculations of any mechanical component must be checked if the design considerations based on a specific standard. Practically, there are two ways of checking procedure. First, comparing the induced stresses by using the existing stress equation related to that component. The second is the stress analysis using finite element method. The two approaches are used here for the purpose of checking.

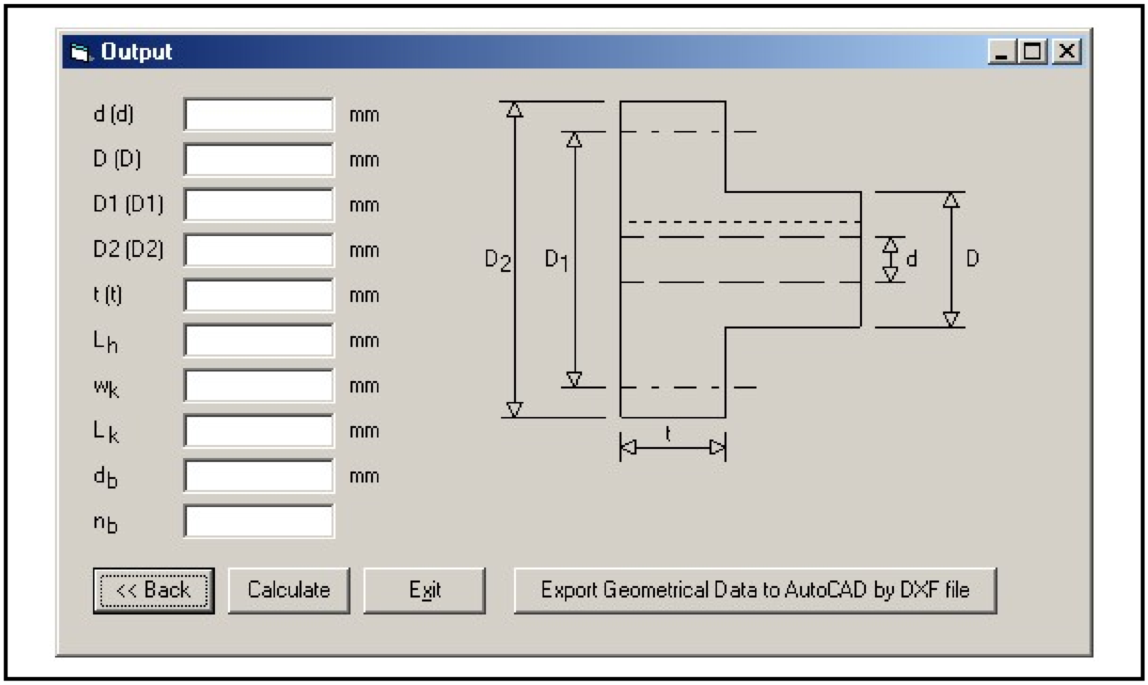


Fig. (3) : output of this program is the real dimension of all the flange components

The first approach for checking is based on the following stresses equations [7]:

1. Checking hub diameter (D)

$$\tau_{f_1} = \frac{16T}{\pi D^3(1-k)} \quad \text{………………} \quad (3)$$

2. Checking flange thickness (t)

$$\tau_{f_1} = \frac{2T}{\pi D^2 t} \quad \text{……………………} \quad (4)$$

The design is assumed to be acceptable if the induced stresses is less than or equal to the permissible stresses.

The bolts are designed based on two types of stresses as follows [7]:

- Based on shearing stress

$$d_b = \sqrt{\frac{8T}{\pi \tau_{bp} D_1 N}} \quad \text{………………} \quad (5)$$

- Based on crushing stress

$$d_b = \sqrt{\frac{2T}{\sigma_{cbp} D_1 t N}} \quad \text{……………… (6)}$$

In this case the maximum produced diameter is selected to avoid failure.

The key is assumed to be square. The design for key is also based on two types of expected failure as follows [8]:

- Based on shearing

$$L = \frac{2T}{\tau_{kp} db} \quad \text{…………………… (7)}$$

- Based on crushing

$$L = \frac{4T}{dh\sigma_{ckp}} \quad \text{…………………… (8)}$$

The maximum length is selected to avoid failure.

The algorithm of this software program may be summarized as follows:

Algorithm of the Design flange coupling

1. Input T, if it is not available input p and w
2. Selected proper flange coupling material
3. Calculate d (equation 2)
4. Let
   D = 2d
   t = 0.5 d
   $D_1 = 3\ d$
   $D_2 = 4\ d$
5. Select n_b according to the value of d (Table 1)
6. Check D (equation 3)
   If $\tau_{fI} > \tau_{fp}$
   - Yes, make iteration around τ_{fI} by increasing D and terminate iteration when $\tau_{fI} \leq \tau_{fp}$
   - No, Go to step 7
7. Check t (equation 4)
   If $\tau_I > \tau_p$
   - Yes, make iteration around τ_{fI} by increasing t and terminate iteration when $\tau_{fI} \leq \tau_{fp}$
   - No, Go to step 8
8. Calculate d_b (equation 5)
9. Calculate d_b (equation 6)
10. Take the maximum d_b from step (8) & (9)
11. Calculate L (equation 7)
12. Calculate L (equation 8)
13. Take the maximum L from step (11) & (12)
14. Let $L_h \geq L$

End of algorithm

The second approach (finite element analysis) will be discussed later in the model analysis (section 4).

The Translator Program

The objective of this program is to automatically translate (convert) the obtained geometrical design data into a descriptive (graphical) data, which represent the final product. This task can be done by building a software program for construction of 2D DXF file structure.

This software program is capable of:

- Processing the geometrical design data and exporting them as a DXF code to AutoCAD package [9] using Visual Basic programming language [10].
- Visualization of the final product in real dimensions in multi views of drawing.
- Viewing the basic dimensions of the flange.

Appendix (A) contains a simple output of DXF format code.

Model Analysis

In order to check the ability of the design product in exerting the applied torque, the final product is analyzed using the finite element method.

The finite element model is constructed using MATLAB Programming Language [11].

The applied torque is converted to two equivalent opposite loads and applied at the surface of the hub. The applied load can be determine using the following formula:

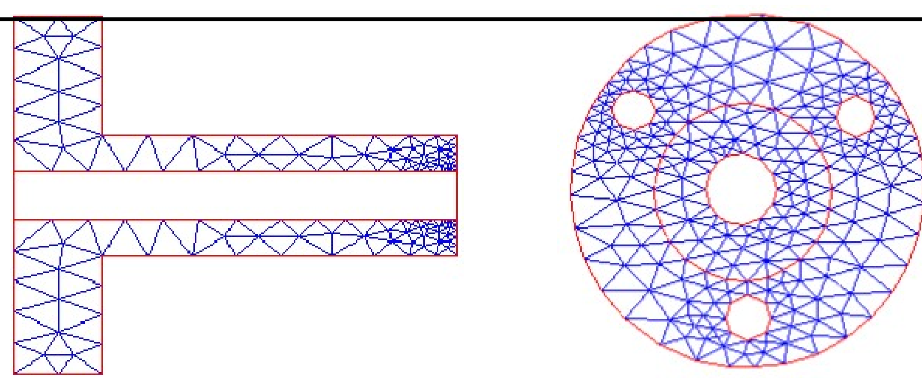
$$F = \frac{2T}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

The mesh is generated according to the following mechanical properties:

$E = 196 * 10^3$ *Mpa*

$\upsilon = 0.3$

Figure (4.a) and (4.b) shows front section and side view of the meshed model respectively.



-a- -b-

Fig . (4) : distribution of shear stress contours (a)with right angle corner (b)with filleted

Results and Discussion

To show the validity of our approach and for the purpose of completeness, an illustrative design example is introduced here.

Figure (5) shows the input frame and selected physical parameter for the generation of geometrical design data.

Figure (6) shows the output frame, which shows all the geometrical design data of flange coupling components. In this figure the geometrical data can be exported to the AutoCAD package by clicking the "Expert geometrical data to AutoCAD by DXF file" command.

Figure (7) shows the exported data as a final product through out the translator program. This figure shows the final product with different views and dimensions.

Figure (8) shows the finite element model of the generated product and the direction of the applied couple.

To analyze the meshed model, the applied couple (F) at the top surface of the hub is calculate as follows:

$$F = \frac{2 \times 300}{50 \times 10^{-3}}$$

F = 12 KN

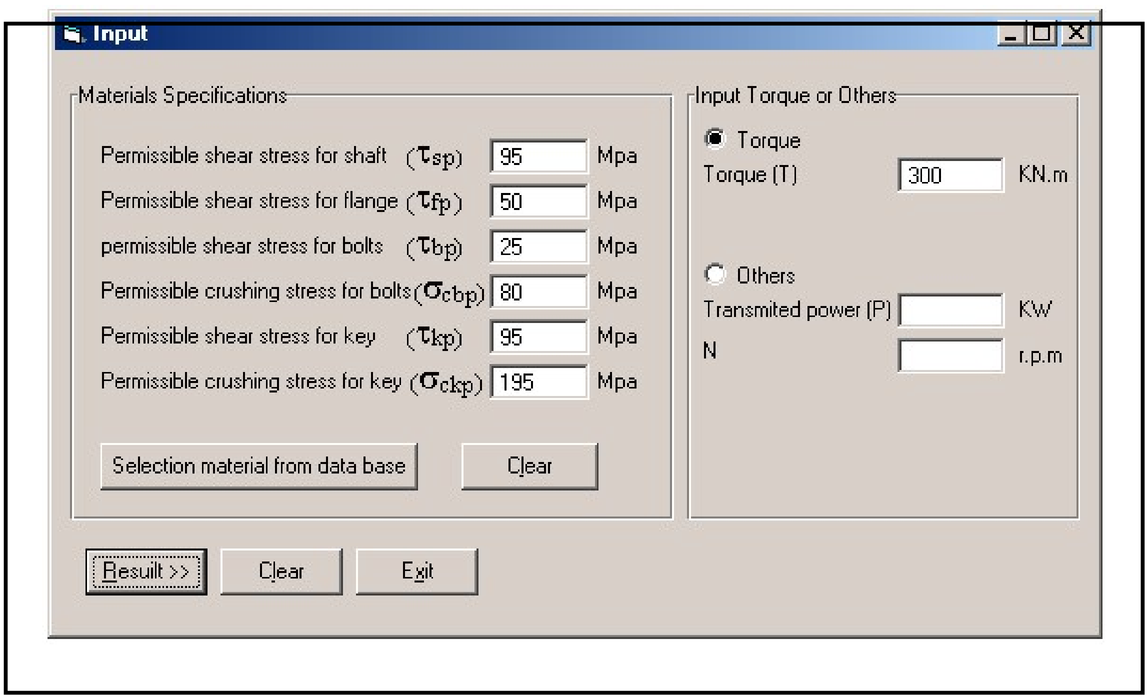


Fig. (5) : the proposed input frame

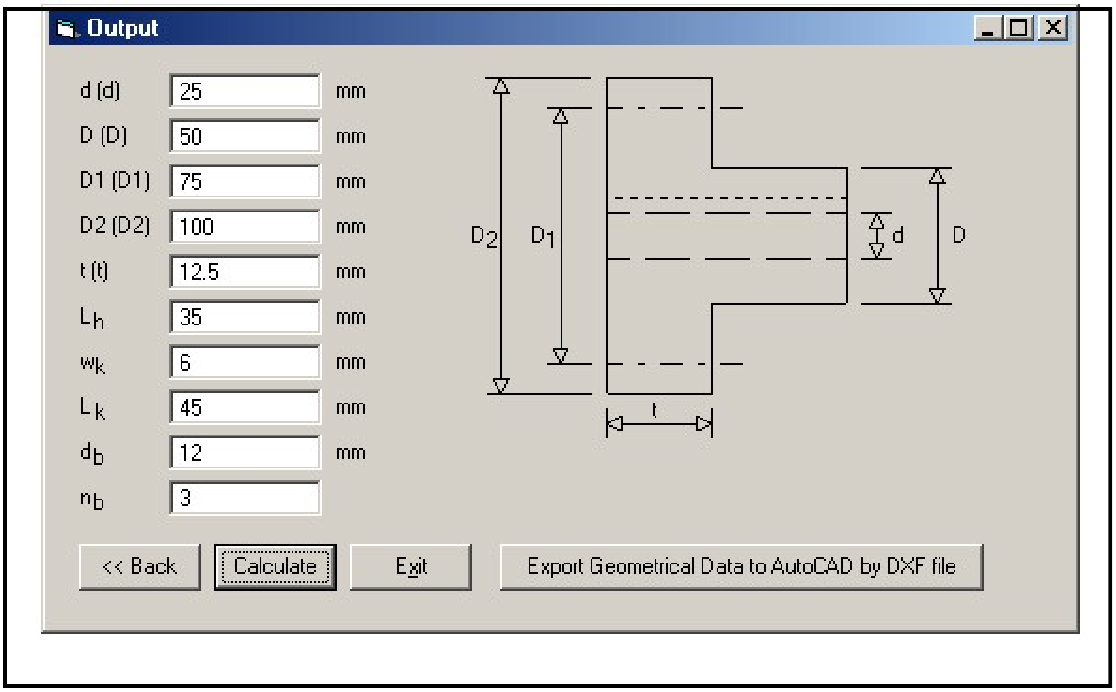


Fig. (6) : the output geometrical data and graphic

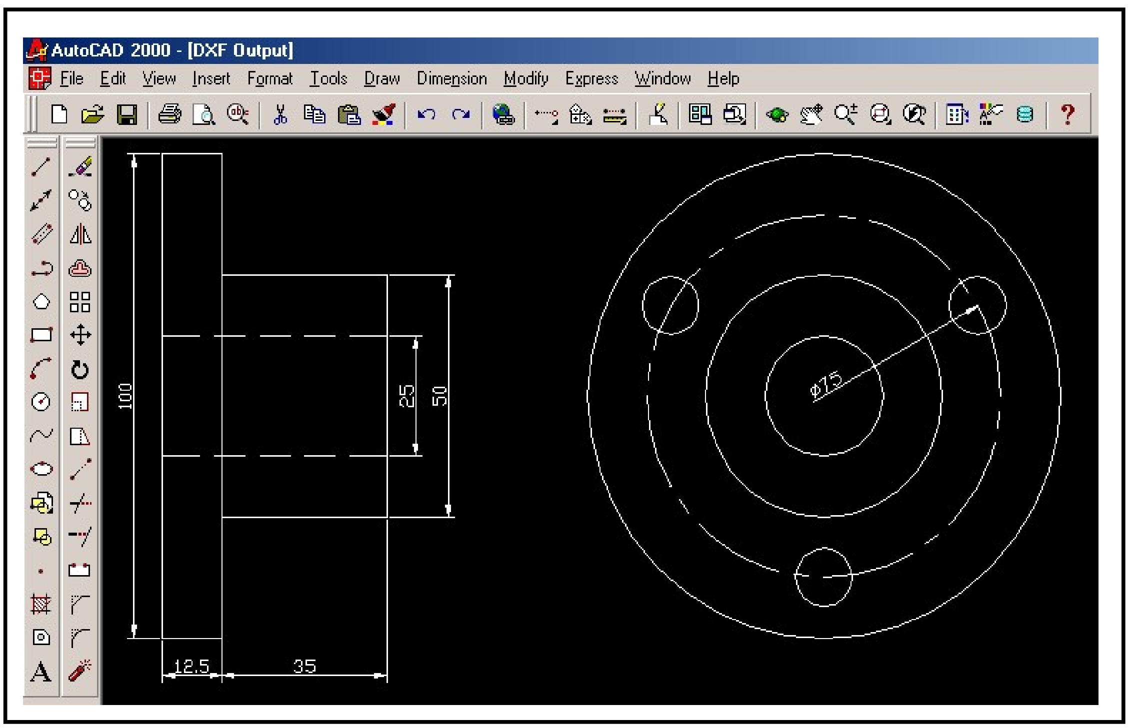


Fig. (7) : different views and dimensions of the final product

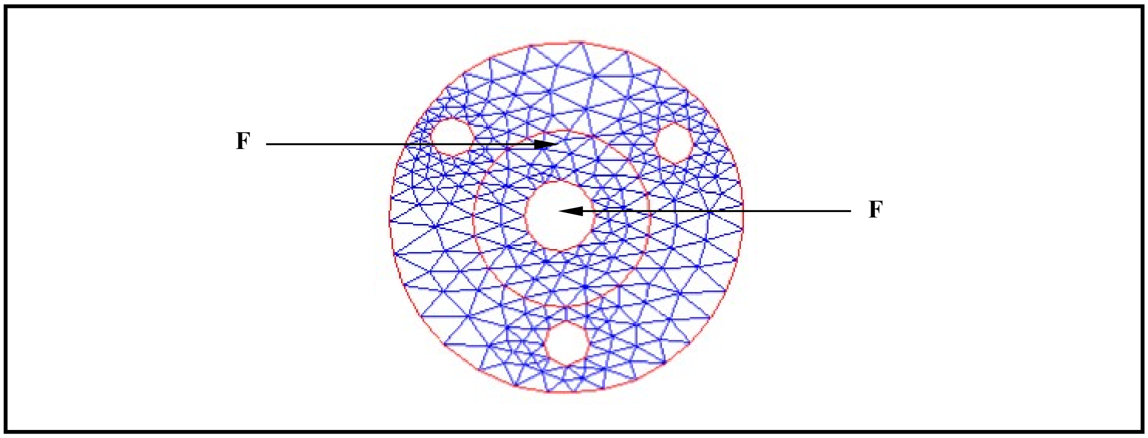


Fig. (8) : the applied couple of meshed model

Figure (9-a) depicts the resulted x-y shear strain of the FEA of this model. From this figure, it is worth noting that the maximum shear strain(γ_{x-y}=0.1) sinks at the intersection between hub and flange due to the sudden change in cross-sectional area which in turn resulting in concentration of stresses at this region. To overcome the problem of stress concentration the sharp edge can be filled using a filleted radius of (r_f =5mm). This modification in the geometry of hub-flange intersection may reduce the maximum shear strain to (γ_{x-y} =0.03) as shown in figure (9-b).

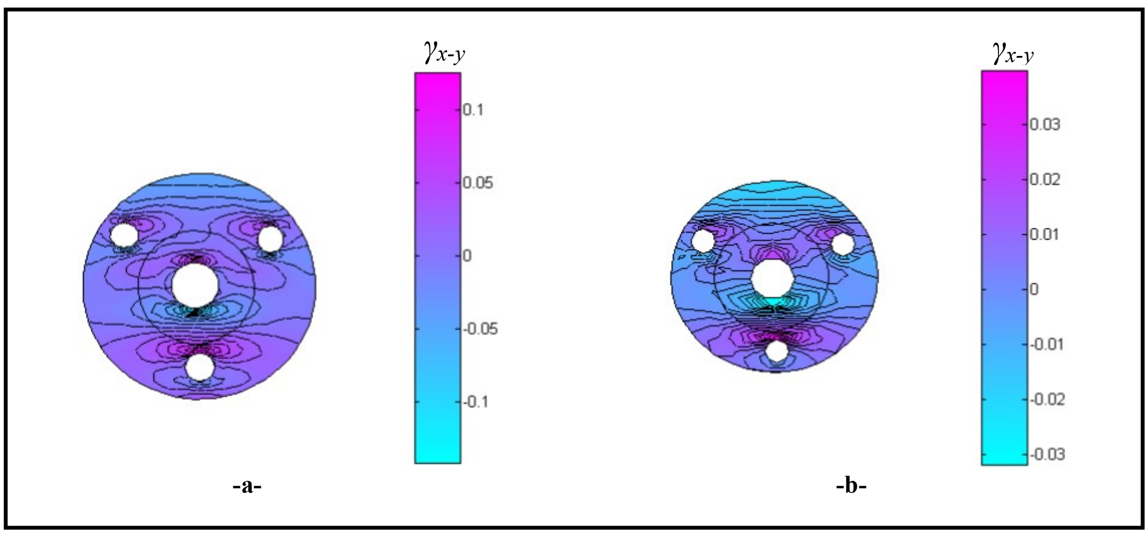


Fig. (9) : the distribution of shear strain contours (a) of sharp edge model. (b) of filleted model.

The distribution and values of shear stresses of the sharp edge model and filled model are shown in figure (10-a) & (10-b) respectively. From these two figures it is observed that the filleted model reduced the maximum induced shear stress from (12Mpa for the sharp edge model) to (10Mpa for the filleted model), i.e. a reduction up to 17% in the maximum induced shear stress can be produced by changing the geometry of the hub-flange intersection.

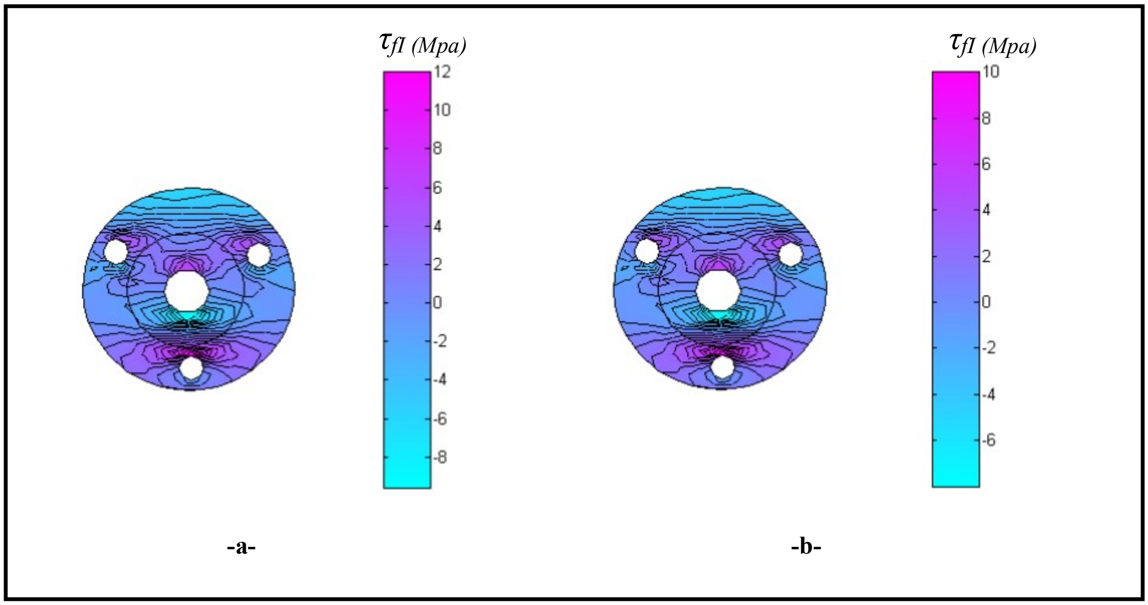


Fig. (10) : the distribution of shear stress contours (a) of sharp edge model (b) of filleted model

Another important result may be gathered from these two figures, that is the maximum induced shear stress for both modified and unmodified model is much smaller than the permissible stress of flange material.

Conclusions

For the purpose of utilizing the existing CAD system, examining the versatility of the design process and simplifying the analyses of the design product, the integration between well-developed CAD systems and a proposed software program may be a very important task. In this paper, we construct a software program for generation of a mathematical geometrical design data and a software program to convert these data to the AutoCAD package through the DXF file code. In particular, the following remarks may be concluded:

1. The translator software program is very efficient in the visualization of the designed object in different views.
2. The DXF file code may be a good way to translate the geometrical data to graphical data.
3. The analyzed model using FEM approach shows that the designed object is accepted to prevent the future failure, since that the induced stresses is smaller than the permissible stresses.
4. The sharp edge tends to concentrate stresses. Changing the geometry of this edge in a suitable shape result in a large reduction in the induced stresses. This result can be translated to life service and reliability.

Appendix -A-

DXF Output

'	31	0	31	100
SECTION	0.0	**LINE**	0.0	AcDbCircle
2	0	5	0	10
ENTITIES	**LINE**	2A	**CIRCLE**	140.0
0	5	330	5	20
LINE	27	2	2E	50.0
5	330	100	330	30
24	2	AcDbEntity	2	0.0
330	100	8	100	40
2	AcDbEntity	0	AcDbEntity	12.5
100	8	6	8	0
AcDbEntity	0	**DASHED2**	0	**CIRCLE**
8	100	100	100	5
0	AcDbLine	AcDbLine	AcDbCircle	33
100	10	10	10	330
AcDbLine	0.0	0.0	140.0	2
10	20	20	20	100
12.5	0.0	37.5	50.0	AcDbEntity
20	30	30	30	8
0.0	0.0	0.0	0.0	0
30	11	11	40	100
0.0	12.5	47.5	50.0	AcDbCircle
11	21	21	0	10
12.5	0.0	37.5	**CIRCLE**	107.5240473580835
21	31	31	5	20
100.0	0.0	0.0	2F	68.75
31	0	0	330	30
0.0	**LINE**	**LINE**	2	0.0
0	5	5	100	40
LINE	28	2C	AcDbEntity	6.0
5	330	330	8	0
25	2	2	0	**CIRCLE**
330	100	100	6	5
2	AcDbEntity	AcDbEntity	**CENTER2**	34
100	8	8	100	330
AcDbEntity	0	0	AcDbCircle	2
8	100	6	10	100
0	AcDbLine	**DASHED2**	140.0	AcDbEntity
100	10	100	20	8
AcDbLine	12.5	AcDbLine	50.0	0
10	20	10	30	100
12.5	25.0	47.5	0.0	AcDbCircle
20	30	20	40	10
100.0	0.0	62.5	37.5	172.4759526419164
30	11	30	0	20
0.0	47.5	0.0	**CIRCLE**	68.75
11	21	11	5	30
0.0	25.0	0.0	31	0.0
21	31	21	330	40
100.0	0.0	62.5	2	6.0
31	0	31	100	0
0.0	**LINE**	0.0	AcDbEntity	**CIRCLE**
0	5	0	8	5
LINE	29	**LINE**	0	35
5	330	5	100	330
26	2	2D	AcDbCircle	2
330	100	330	10	100
2	AcDbEntity	2	140.0	AcDbEntity
100	8	100	20	8
AcDbEntity	0	AcDbEntity	50.0	0
8	100	8	30	100
0	AcDbLine	0	0.0	AcDbCircle
100	10	100	40	10
AcDbLine	47.5	AcDbLine	25.0	140.0
10	20	10	0	20
0.0	25.0	47.5	**CIRCLE**	12.5
20	30	20	5	30
100.0	0.0	75.0	32	0.0
30	11	30	330	40
0.0	47.5	0.0	2	6.0
11	21	11	100	0
0.0	75.0	12.5	AcDbEntity	ENDSEC
21	31	21	8	0
0.0	0.0	75.0	0	EOF

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