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An Inter-Active Software for the Design of Power Screws

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Abstract
This paper presents software that was developed at KAAU for the analysis and design of power screws. The program enables the user to substantially compute the screw diameter of a power screw to be designed, or to find the safety factor for a given loading on an existing power screw, or to find the permissible load for the same. The software takes into account strength and instability conditions as well as the geometry, boundary conditions, collar-nut arrangements, number of starts, thread profiles, screw and nut materials, loading arrangements and coefficients of friction. The outputs from the program include efficiency, geometry, the required torque, working stresses as well as the sought parameters. It is considered therefore that PowerScrew possesses the potential to become an effective tool for the student of engineering as well as for the practicing engineer.

Key Words: screw, nut, power screw, permissible load, thread, friction coefficients, safety factor, design

1. Introduction

Power screws, also called linear actuators and translation screws, come in two basic categories namely, lead screws, which have sliding contact between the nut and screw, and ball screws, which operate on rolling contact. Sliding contact assemblies typically use nuts made of internally lubricated plastic or bearing grade bronze. Ball screw assemblies use re-circulating ball bearings that roll along the helical grooves in the screw and nut. The present study deals with lead screws.

Multi-start threads are widely used in various branches of engineering, particularly as kinematic devices and power-transmitting screws. Standards were established (Bykhovskii, 1977) for basic dimensions and tolerances for trapezoidal multi-start threads. The Comecon Standard 185-75 applies to general-purpose trapezoidal multi-start threads and defines the basic parameters and tolerances for threads of diameter from 10 to 320 mm, pitch from 2 to 48 mm, advance per turn from 4 to 240 mm, profile angle 30 degrees, and number of starts from 2 to 8.

Power screws, with their less-complicated design, can be made in-house or purchased from a number of different sources, unlike ball screws, which are manufactured by only a handful of facilities worldwide. Furthermore, power screws can be made from a wide variety of materials, such as nonferrous metals and plastics, because these parts do not have to be hardened.

Lipsett (2000) reviewed the use and design of power screws. Bykhovskii (1977) presented a review of multi-start power screws, and discussed the Comecon standards. A comparison of power screws versus ball screws was given by Lochmoeller (1976). El-Sayed and Khataan (1974, 1975, 1976, 1976a) investigated the load-carrying capacity of power screws.

Perhaps the first attempt to develop a computer program for the design of power screws was recorded by Borm and Kinzel (1986).

In what follows we introduce PowerScrew, which is a Windows-based software package in Visual Basic for the analysis and design of power screws.

2. The PowerScrew Package

Figure 1 shows the icon of PowerScrew. When clicked, the user accesses the main screen (Fig. 2) of the software which enables the analysis and design of power screws.

Fig. 1. The icon of PowerScrew.

The main screen prompts the user to declare his objective by opting to determine

a) the diameter of the spindle screw (Fig. 2), or
b) the factor of safety of a power screw for a given configuration (Fig. 2a), or

c) the permissible load on a power screw subjected to certain conditions (Fig. 2b).

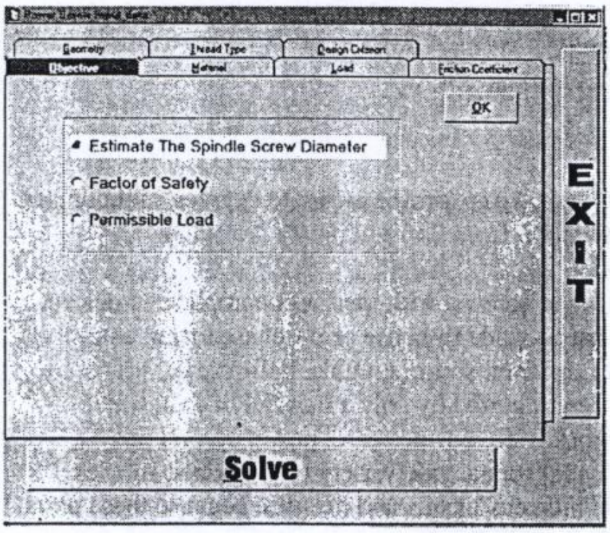


Fig. 2. The main screen of PowerScrew.

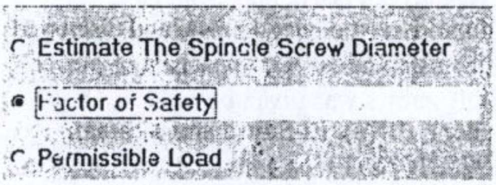


Fig. 2a. Selection of the determination of factor safety as the objective.

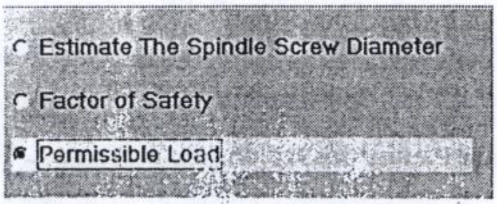


Fig. 2b. Selection of the determination of the permissible load as the objective.

Aside from the formulation of the objective itself, the top two lines of tabs on the main screen call for the specification of materials, loads, friction coefficients, the geometries, thread types and the design criteria. Clicking on the OK button in Fig. 2 leads to the next tab and the screen associated with it. Invoking the EXIT button on the right terminates work on PowerScrew, whereas clicking on the SOLVE button at the bottom of the main screen activates the main engine of the software.

Once the objective is determined, the user clicks on the OK button to move to the next screen, which is a menu for the selection of materials (Fig. 3). This menu allows the specification of the material and its characteristics for both the screw and the nut of the power screw. Thus invoking the downward facing arrow button at left gives rise to a pop-down menu that contains a number choices of SAE/ISO standard materials. Clicking on any one of these choices results in the updating of the figures corresponding to the ultimate tensile strength and yield strength of the selected material, in their respective windows. In case the user wishes to specify a material which does not exist on the pop-down menu, he is given the freedom to type the corresponding strength values in the appropriate windows.

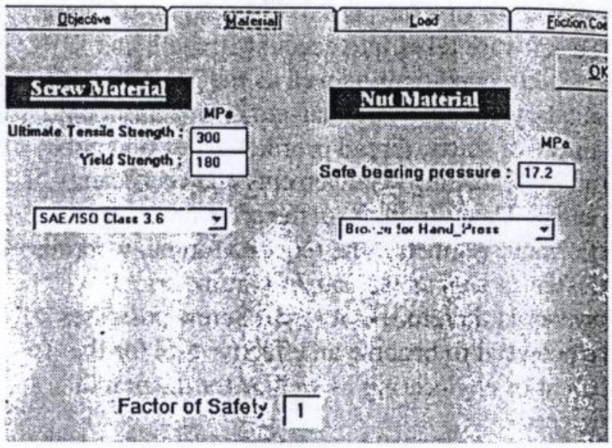


Fig. 3. The menu for the specification of materials.

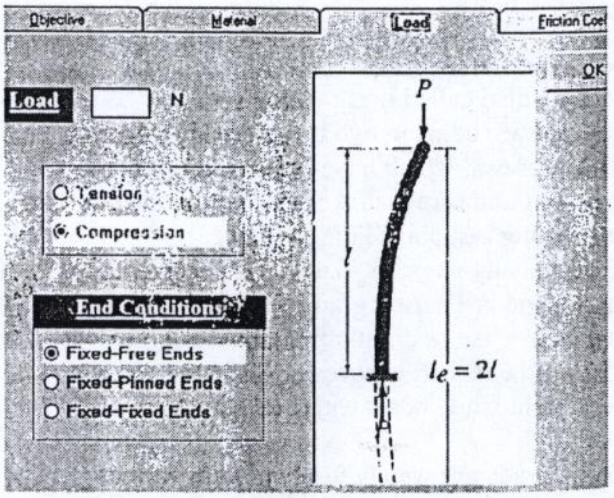


Fig. 4. The menu for the specification of loading conditions.

In similar manner, clicking on the downward facing arrow on the right side of the menu displays a number of choices of material for the nut and its safe bearing pressure. In case the user wishes to specify a material which does not exist on the pop-down menu, he is given the freedom to type the corresponding safe bearing pressure in the window for the material of his choice.

A small window located at the bottom of the menu of Fig. 3 asks the user to specify a safety factor for the design, in case the objective is other than the determination of the safety factor.

Clicking next the OK button on the menu of Fig. 3 opens the menu of Fig. 4, where the loads are specified.

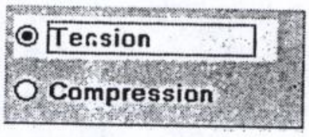


Fig. 4a. Specification of a power screw in tension.

The first window on the top left of this menu prompts the user to specify the applied load, in case the objective is other than the determination of the safe load. Then there are radio buttons to indicate whether the loading is going to be tensile (Fig. 4a) or compressive (Fig. 4).

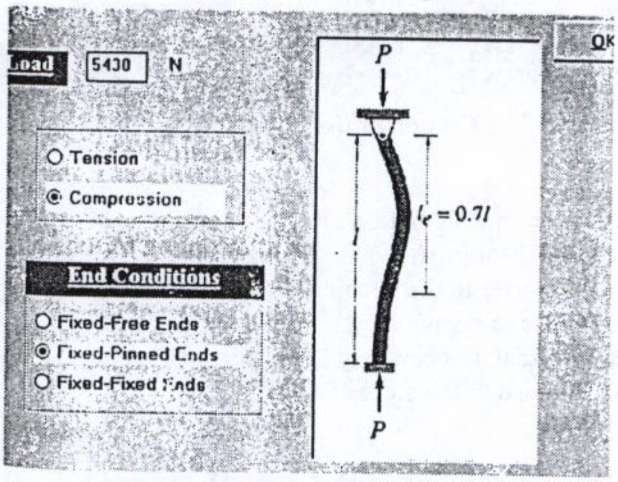


Fig. 4b. Power screw with fixed-pinned ends.

The three radio buttons at the bottom left of the screen allow the specification of the end conditions. The picture on the right half of the screen changes to reflect the selected end condition for the power screw. Thus Fig. 4 indicates the condition where one end of the power screw is free while the other end is fixed. Figure 4b shows the case for a power screw where one end is pin-jointed and the end is fixed, and Fig. 4c illustrates the case when both ends of the power screw can be considered as fixed.

Invoking next the OK button on the menu of Fig. 4 leads to the menu for specifying the coefficients of friction (Fig. 5) between the threads of the screw and its nut as well as that between the screw and the thrust collar (Fig. 6), which is the interfacing element between the power screw and the environment on which it acts. Each coefficient can be increased or decreased by the use of the up-and-down arrows. The user can also type in the values of his choice for the coefficients of friction.

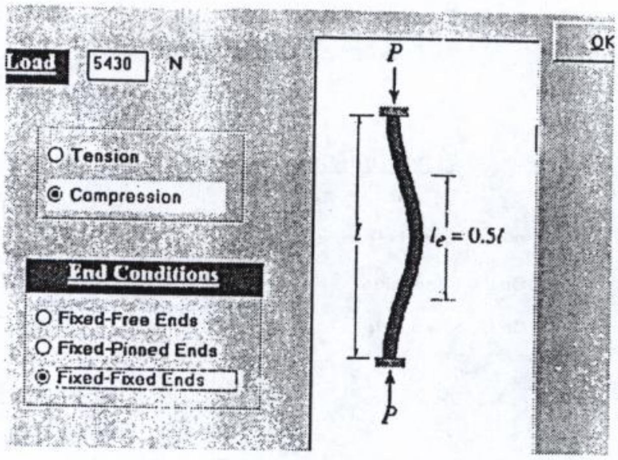


Fig. 4c. Power screw where both ends are considered fixed.

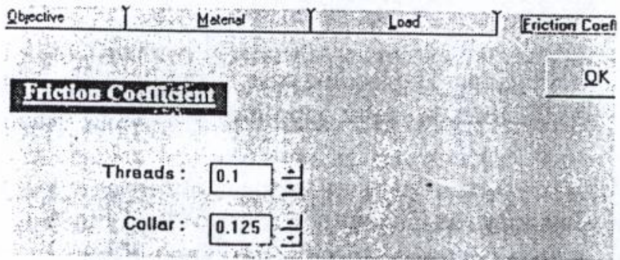


Fig. 5. The menu for the specification of coefficients of friction.

Clicking on the OK button in the menu of Fig. 5 pops up the menu of Fig. 6, where the user is prompted to specify where on the power screw the external force is applied. In case the load is applied via the collar as shown in Fig. 6, then the thrust collar and the threads are said to be on the same side. In case the collar is located on the other end of the screw, as shown in Fig. 6a, then the collar and the threads are said to be on opposite sides. At this point the user specifies the length of the screw as well as the diameter of the circular contact surface between the load-bearing collar and the load.

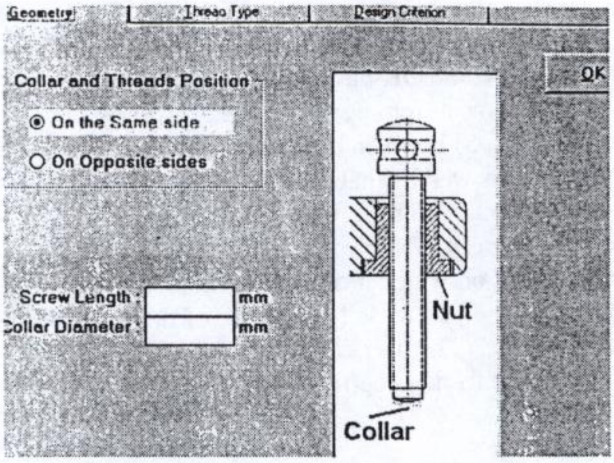


Fig. 6. Specification of the geometry of the power screw.

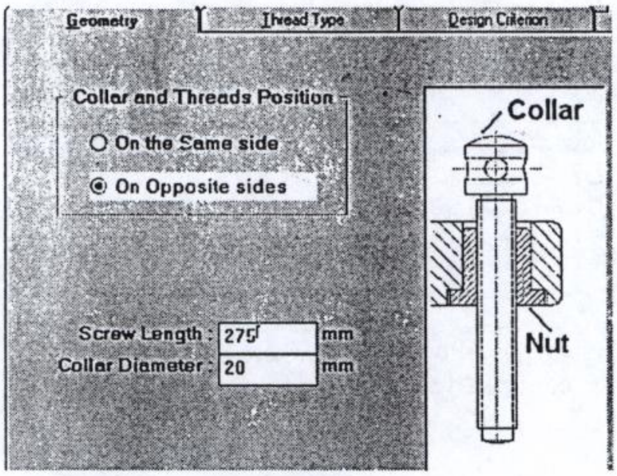


Fig. 6a. The loading case where the collar and the threads are on opposite sides.

Invoking the OK button on the menu of Fig. 6 causes the thread specification menu of Fig. 7 to appear. Here either the single-thread option can be selected or the double-thread option (Fig. 7a), along with the specification of one of four thread types (Fig. 7b).

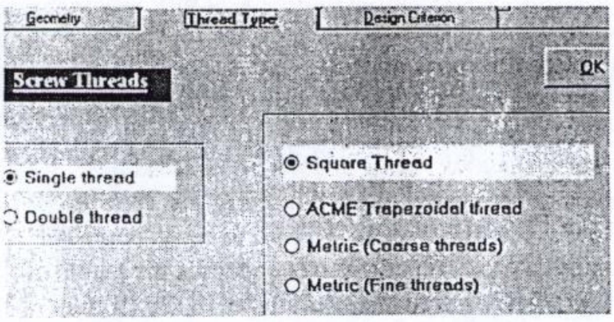


Fig. 7. Specification of threads.

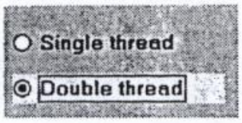


Fig. 7a. Selection of single or double thread type of screw.

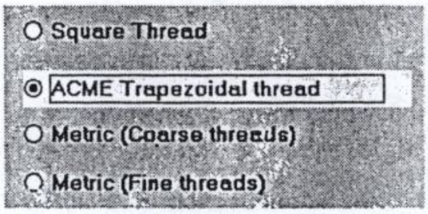


Fig. 7b. The four types of thread available for use on power screws.

Invoking next the OK button in the menu of Fig. 7 results in the displaying of the menu of Fig. 8 where the user can select the design failure theory of his choice.

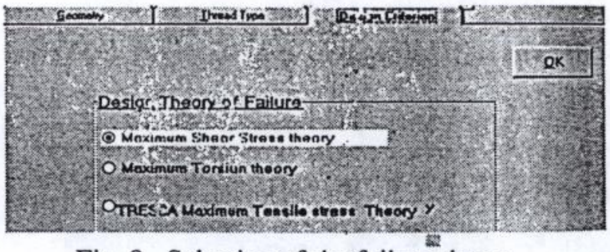


Fig. 8. Selection of the failure theory.

Clicking on the OK button after opting for one of the failure theories shown in the menu of Fig. 8 returns the user to the opening screen of Fig. 9, which is the same as Fig. 2. This is a clear indication that all necessary input information has been provided to the software.

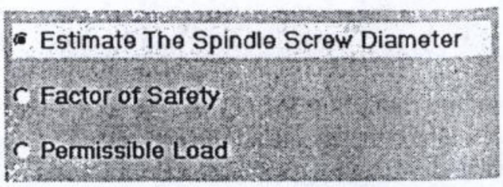


Fig. 9. The menu that indicates that all input information has been entered.

In case the SOLVE button (Fig. 2) is invoked before the submission of all required information, the program responds with a number of warning messages. Some of these are displayed in Fig. 9a.

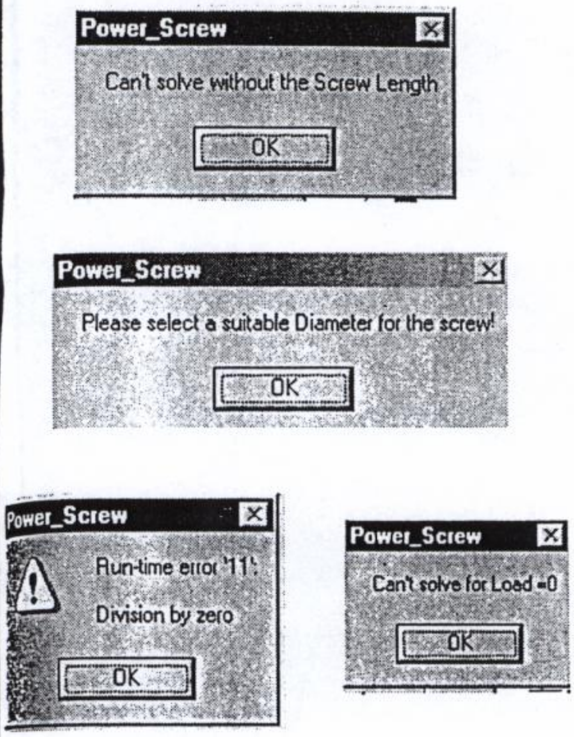
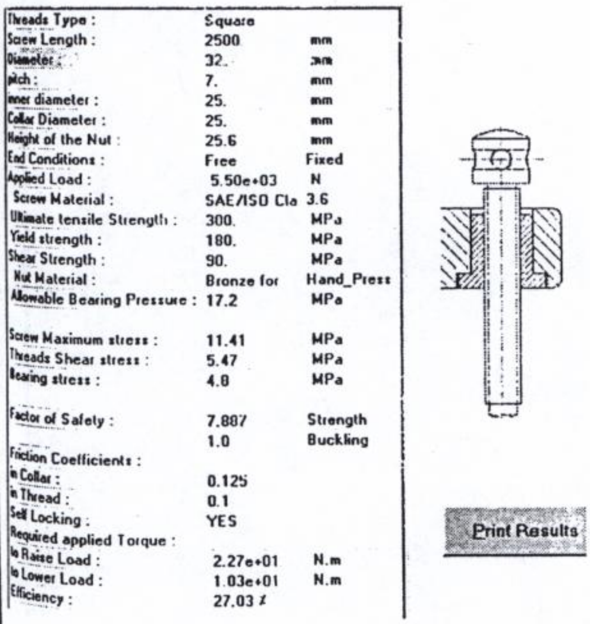


Fig. 9a. Some of the error and warning messages displayed during computation.



Threads Type :	Square	
Screw Length :	2500	mm
Diameter :	32.	3im
pitch :	7.	mm
inner diameter :	25.	mm
Collar Diameter :	25.	mm
Height of the Nut :	25.6	mm
End Conditions :	Free	Fixed
Applied Load :	5.50e+03	N
Screw Material :	SAE/ISO Cla	3.6
Ultimate tensile Strength :	300.	MPa
Yield strength :	180.	MPa
Shear Strength :	90.	MPa
Nut Material :	Bronze for	Hand_Press
Allowable Bearing Pressure :	17.2	MPa
Screw Maximum stress :	11.41	MPa
Threads Shear stress :	5.47	MPa
Bearing stress :	4.8	MPa
Factor of Safety :	7.887	Strength
	1.0	Buckling
Friction Coefficients :		
in Collar :	0.125	
in Thread :	0.1	
Self Locking :	YES	
Required applied Torque :		
to Raise Load :	2.27e+01	N.m
to Lower Load :	1.03e+01	N.m
Efficiency :	27.03 ℅	

Fig. 10. The results menu.

When the SOLVE button is invoked after reaching Fig. 9, the solver engine is activated, as a consequence of which the results menu of Fig. 10 is displayed. The results menu summarizes the input information, and also displays the results of essential design computations. A yellow band emphasizes the result for the selected design objective (*diameter* = 32 mm in Fig. 10, and *factor of safety* in Fig. 10a). In case the design leads to failure, a special message is displayed to emphasize the result (Fig. 10b). Clicking on a button on the lower right of the results menu enables the printing of the results.

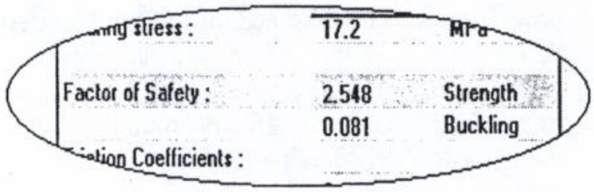


Fig. 10a. Emphasizing band to show the factor of safety.

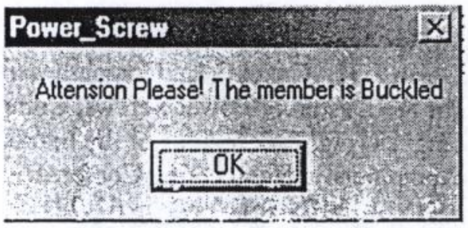


Fig. 10b. Special message indicating failure of the screw in buckling.

3 Concluding Remarks

Power screws are mechanical elements of considerable significance that are used to convert rotary motion of either the nut or the screw to relatively slow and precise translatory motion, as in the case of the lead screw of a lathe. Substantial use of power screws is also witnessed in vices, C-clamps, mechanical testing machines, screw jacks and presses to apply large forces. As such power screws deserve considerable attention in contemporary engineering design.

Power screws, with their less-complicated design, can be made in-house or purchased from a number of different sources, unlike ball screws, which are manufactured by only a handful of facilities worldwide. Furthermore, power screws can be made from a wide variety of materials, such as nonferrous metals and plastics, because the parts do not have to be hardened.

Power screws must have adequate strength to withstand axial loads as well as applied torques. The types of stresses induced on the screw can be direct tensile or compressive stress due to an axial load, torsional shear stress, shear stress due to axial load, and bearing pressure. The design engineer must carry out a number of computations involving thread types, screw and nut materials, friction coefficients, and the loading geometry. The present software, PowerScrew, enables the engineer to substantially compute the screw diameter of a power screw to be designed, or to find the safety factor for a given loading on an existing power screw, or to find the permissible load for the same. PowerScrew can be an effective tool, therefore, for the student of engineering as well as for the practicing engineer.

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