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THEORETICAL REVIEWS ON HOW TO IMPROVE THE DEGREE OF EFFICIENCY ON POWER SCREWS

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ABSTRACT
A frequently repeated machine element in almost every mechanical design, regardless of the field of use, is the power screw (leadscrew). It`s main purpose is to transform rotary motion into linear, and vice versa, whereat the last mentioned option is rarely used since self-locking of the power screw is no longer provided. Every machine element has different advantages and disadvantages but all come together in one unique technical parameter which is valid for every machine, the degree of efficiency. Irrespective of many advantages power screws have, it`s wider use in other applications is restricted due to it`s low degree of efficiency. This paper should give some theoretical proposals on how to increase the degree of efficiency on power screws. Authors present several ways to increase the degree of efficiency by starting to increase the pitch, changing the thread geometry (profile), assuming a lower coefficient of drag, using multi-start screws and finally giving a suggestion which includes a combination of some mentioned solutions. It is important to emphasize that all mentioned suggestions are solutions through out the design of power screws, not considering tribological phenomenons like coefficient of drag or used material.
Keywords: Power screw, pitch, thread, degree of efficiency

1. INTRODUCTION
A power screw or translation screw is a machine element primarily designed to transform turning motion into linear movement. One of the most common applications in which they are used are different machine tools, presses, vises and maybe the most popular jacks. In order to carry out useful work a powertrain has to be used in conjuction with a nut, whether the nut is stationary or mobile. This very simple construction principle which consists of basically two parts (screw and nut) entails several advantages such as: large load carrying capability, minimal number of parts, smooth, and low maintenance, relative easy to manufacture (no specialized machinery is required), self-locking capability etc. Due the fact that power screw nut and screw mate each other with rubbing surfaces the produced friction is much higher compared to other machine elements which mate with rolling surfaces such as bearings. This is the main reason why the degree of efficiency for power screws is between 25 and 70 %. Due to the low degree of efficiency, power screws can not be used in continuous power transmission applications. This high friction causes the threads to wear out very quickly and the nut or screw had to be replaced. This thread wear can be reduced to a certain extent by changing the thread geometry (profile). According to this, power screws are classified by their thread

geometry. The most common are the V, Acme and Buttres profiles. All these profiles are dirived from the basic thred profile for power screws, which is the square thread. The square thread profile is the most efficient having the least friction but they are the most difficult to machine so that they are used just for screws that carry high power. The Acme profil has a 30 ° profile angle which makes it easier to manufacture but has increased friction caused by the profile angle. Buttress threads have a 3 ° profile angle which makes them as efficient as square threads but are easier to manufacture. It`s disadvantage is that it is used where the load force on the screw is only applied in one direction.

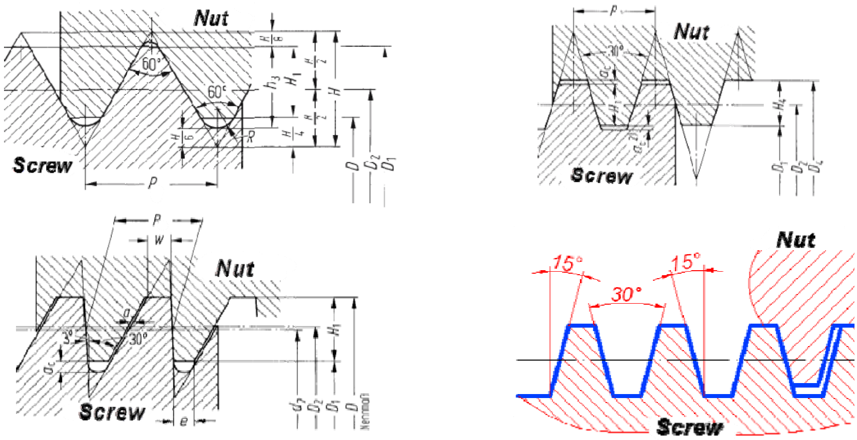

Figure 1. Different thread profiles a) V thread b) Acme thread c) Buttress thread d) New thread

It should be noted that V-threads are less suitable for power screws than other thread profiles such as Acme because they have more friction between the threads. Their threads are designed to induce this friction to keep the fastener from loosening where the power screw follows a totally different design concept which implies to hold the friction low and so, raise up the efficiency. All thread parameters such as Pitch, thread profile angle, root deepness etc. become visible in the final equation for the degree of efficiency of a power screw (equation 1). The degree of efficiency for lowering a load or moving downwards is presented by equation 2.

$$\eta_{lift} = \frac{tg\alpha}{tg(\alpha+\rho)} \tag{1}$$

$$\eta_{lower} = \frac{tg(\alpha-\rho)}{tg\alpha} \tag{2}$$

2. PROBLEM DEFINITION

According to equation (1) the power screw efficiency can be improved with increasing the helix angle α which is typically between 3 ° and 7 ° depending from the angle of friction (ρ) which is directly related to the coefficient of friction ($\tan\rho=\mu$). When plotting the efficiency (η) function in relation to the helix angle (α) it becomes obvious that the efficiency for power screws dedicated to lower a load, is just possible if it is not self-locking meaning the helix angle (α) is greater than the angle of friction (ρ) (Figure 2). This fact reduces our review just on lifting a load as in the most cases a self-locking capability is required.

As mentioned the efficiency can be improved by increasing the helix angle. To achive this effect, authors used several ways listed below:

- Changing the thread geometry, profile
- Increasing the helix angle
- Reducing the coefficient of drag
- Using multi start-screws

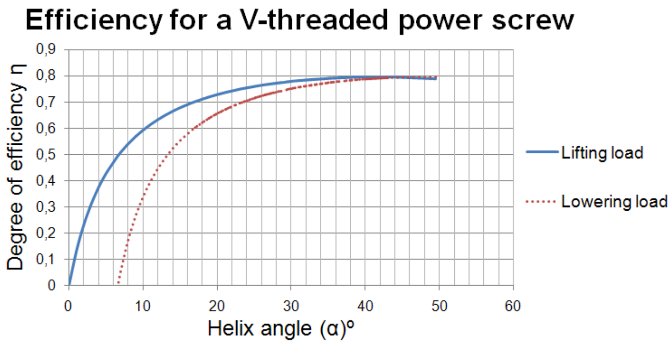

Figure 2. Degree of efficiency plotted against the helix angle for a V-threaded power screw

3. SOLUTION DISCUSSION

To achieve the previously mentioned final goal of increasing power screw efficiency authors first attempt was to change the thread geometry (profile) driven by the fact to lower the friction of a single quirk (Figure 1). The attempt is to keep the profile as nearest as possible to the square profile (because of the lower friction) but at the same time avoid a completely identical profile because of the higher manufacturing cost. The thread profile angle was set to 15 ° with other lightly amended profile dimensions such as pitch, root deepness etc. With the new thread parameters the degree of efficiency was ploted against the helix angle without significant increase of efficiency (η_{max}=81,75 %). Although this way of efficiency improvement should be effective, the real potential to apply this profile would be low because of the huge logistic problems which would cause the introduction of such a new profile. A comparing overview of efficiency for several thread profiles, including the authors "New profile" is given in Figure 3. It is obvious that all possible thread profiles are saturated at the efficiency of about 81 % . Diversity appear at the fourth place behind the comma (Table 1).

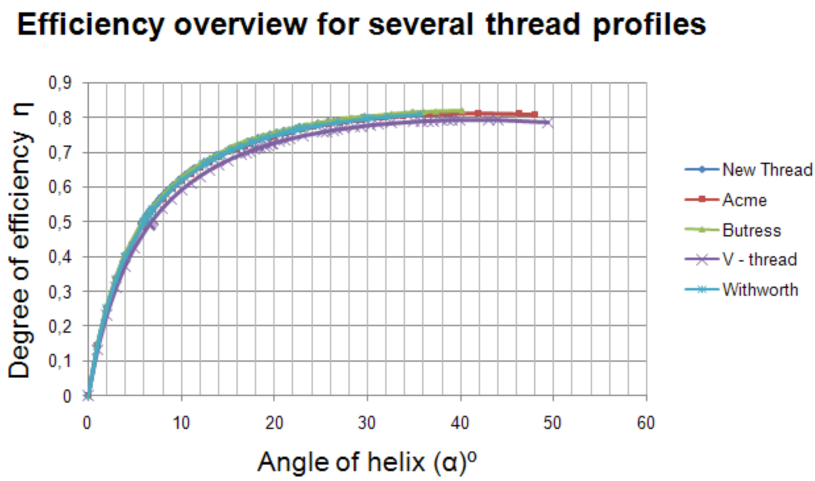

Figure 3. Efficiency comparison between different thread profiles

Regardless of the thread profile, a effective way to improve power screw efficiency is to increase helix angle. This way is often avoided because of the fact that most power screws had to be self-locking. If the helix angle becomes greater than the angle of friction than the power screw loses his self-locking capability. This contradiction between efficiency and self-locking is a constant brake in increasing power screw efficiency. To overcome this hurdle, authors suggest the use of brakes in general terms. This means that a individual brake system had to be designed for each power screw construction

individually. This, off course increases the total number of parts of the whole assembly but gives back a huge benefit in terms of efficiency.
Reducing the coefficient of drag is a insurmountable and multidimensional problem. Reducing friction raises the efficiency but makes self-locking less possible. Investigation of the drag coefficient is a topic which largeness overcomes this paper. But still if it would be possible to keep it very small and to reduce wear the request for self-locking must be ignored.
A design measurment that also could improve power screw efficiency would be to use multi-start screws. This means that the same geometric profile of a thread is etched more times per one revolution. Every single thread means one pitch, so if there is a three-start screw that would mean that at the same axial length we would have a three times bigger total pitch. With a greater total pitch, helix angle would grow and so the final degree of efficiency (Equation 1). The greatest disadvantage would be the manufacturing cost. Depending on the individual case a estimation should be made to evaluate the cost effectiveness of such a attempt although it is a theoretical way to increase the efficiency wihtout distorting self-locking capability.

Table 1. Maximum degree of Efficiency overview for several thread profiles according to equation (1)

Thread profile	Withworth	V	Butress	Acme	New profile
Theoretical maximum Degree of efficiency %	**81,33**	**79,41**	**81,89**	**81,32**	**81,75**

4. DISCUSSION AND SOLUTION PROPOSAL

Due the fact of small practical degree of effciency (in practice <50%) there have been several alternatives to raise power screw efficiency. One of them predicts the use of ball and roller screws. Although with this approach a efficiency degree of nearly 85 % is achieved, the high manufacturing cost and design complexity prevent it from wider use.
The main problem is left until today. How to improve power screw effectiveness? Considering all the above mentioned solutions, none of the four proposals exclusively could be introduced in operational practice. A new thread profile would be unacceptable from the logistic point of view, where the technical advantage is also negligible because of the maximum theoretical degree of efficiency which slightly differs from other profiles (Table 1).
As mentioned earlier, increasing the helix angle would cause a self-locking inability which is directly related to the attempt to lower the coefficient of drag. Simultaneously, using multi-start screws would be the most satisfactory optimum between economic and pratical benefit, whereat this design feature is mostly used on screws where the axial movement per revolution has to be as much as possible (different assembly tasks). Some power screw applications demand exactly the contrary, where the axial movement per revolution has to be very small (lower pitch) to enable fine-tuning of the final, executive part which is controlled by the power screw.
If all these practical and economical factors are taken into account none of the proposed solutions can be used exclusively. Because of that authors propose a combination in form of using a high helix angle (the maximum theoretic degree of efficiency can be achieved by a helix angle $\alpha=45°-\rho/2$) whereby the self-locking capability would be kept in form of a added brake system. A power screw with a brake system would present a more complex assembly but still less complex then the earlier mentioned roller and ball screws. According to the authors, this would establish a balance between price and practical effectiveness, whereat the power screw efficiency still remains a critical factor in power screw applications.

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