Design Development, Performance Evaluation and Analysis of Compact Drive Self-Locking System- A Review

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Abstract

Lifting applications like's winches and hoist are expected to raise or lower load, the capacity of the device may vary but the primary requirement of safety still remains the same. The load when raised is lifted by the power of motor, but if the motor power is interrupted accidentally then the load will try to reverse the lifter motion and come down which may prove hazardous for safety , in such case a fail safe operation is to be ensured. The conventional method is to use ratchet and pawl arrangement, or a worm and worm-wheel arrangement. These methods though easy to implement are extremely in-efficient (worm-worm wheel efficiency is below 48%). The skewed internal arrangement of mating worms for fail-safe lifting application is a novel method that ensures that the load does not move upward or downward by its own will but also delivers high efficiency there by lowering the power requirements. The shape and arrangement of components makes it compact and easy to use. The paper discusses the analysis of the components that are critical in assembly and also the equipment is tested for torque and power characteristics.

Keywords: Skewed mating screws, fail-safe lifting, efficiency, Self-locking, Torque, Power.

1. Introduction

The Material handling is the basic activity of every manufacturing organization. It has been estimated that unnecessary cost of the product is attributable to material handling activities. Unlike many other operations, material handling adds to the cost of the product and not to its value. It is therefore important first to eliminate or at least minimize the need for material handling and second to minimize the cost of handling. Lifting of load is a major issue in material handling for which it is common to use lifting applications like hoist and winches.

Applications like's winches and hoist are expected to raise or lower load, the capacity of the device may vary but the primary requirement of safety still remains the same. In most gear drives, when driving torque is suddenly reduced as a result of power off, torsional vibration, power outage, or any mechanical failure at the transmission input side, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as back driving. During inertial motion or back driving, the driven output shaft (load) becomes the driving one and the driving input shaft (load) becomes the driven one. There are many gear drive applications where output shaft driving is undesirable. In order to prevent it, different types of brake or clutch devices are used.

However, there are also solutions in the gear transmission that prevent inertial motion or back driving using self-locking gears without any additional devices. The most common one is a worm gear with a low lead angle. In self-locking worm gears, torque applied from the load side (worm gear) is blocked, i.e. cannot drive the worm. However, their application comes with some limitations: the crossed axis shafts' arrangement, relatively high gear ratio, low speed, low gear mesh efficiency, increased heat generation, etc. Also, there are parallel axis self-locking gears. These gears, unlike the worm gears, can utilize any gear ratio from 1:1 and higher. They have the driving mode and self-locking mode, when the inertial or back driving torque is applied to the output gear. Initially these gears had very low (<50 percent).

The term self-locking as applied to gear systems denotes a drive which gives the input gear the freedom to rotate the output gear in either directions but the output gear locks with input when an outside torque attempts to rotate the output in either direction. Worm gears are one of the few gear systems that can be made self-locking, but at the total of efficiency, they rarely exceed 40% efficiency, when made self-locking.

2. Literature Review

Many researchers are working on worm gear and self-locking phenomenon. Padmanabhan. S., Chandrasekaran. M. and Srinivasa Raman. V. (2013) described the worm Gear Drive optimization, also specified design constraints & simplified objective function. in this paper an attempt has been made to obtain optimal solution of Worm gear drive design problem with ACO .Within the various design variables available for a worm and worm wheel design, the power, weight, efficiency and centre distance have been considered as objective functions and bending stress, compressive stress as vital constraints to get an efficient compact and high power transmitting drive. As a future work, minimization of noise and vibration, maximization of gear life can also be included in the objective function to obtain a more dependable gear design and also it can be incorporated to spur, helical and bevel gear designs. Adam Macheta and Sebastian Kania (EC Engineering), in 7th Framework programme, studied about worm gear losses. Their review discussed power losses in worm gears transmissions. A worm drive is a gear arrangement in which a worm (which is a gear in the form of a screw) meshes with a worm gear (which is similar in appearance to a spur gear, and is also called a worm wheel). Like other gear arrangements, a worm drive can reduce rotational speed or allow higher torque to be transmitted. Worm gears are the perfect choice when the need is for producing large motor speed gear reductions in a single step. A single reduction range of 5:1 - 100:1 is considered normal for worm gears.

2.1 Worm gear losses

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Energy losses in worm gears can be divided into four major parts and those are:

- Energy losses from friction
- Energy losses from idler gears
- Energy losses from winding.
- Energy losses from churning
- Energy losses from bearings.

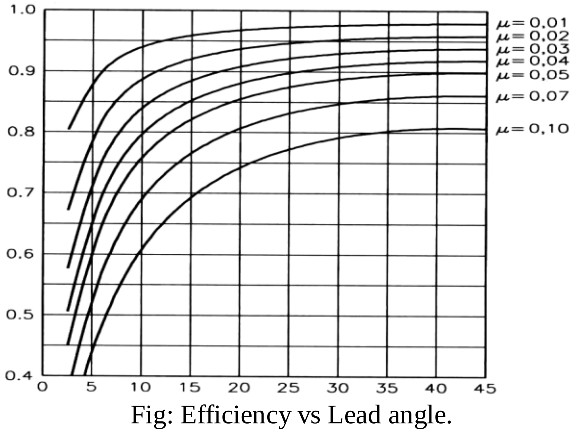
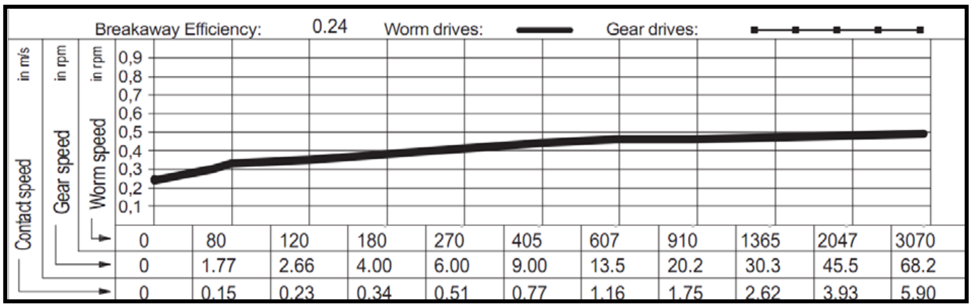


Fig: Efficiency vs Lead angle.



The most important factor in worm gear energy losses are losses from friction which differ from each other when the driving element is the worm and the worm wheel. The efficiency is strictly dependent on the lead angle and the friction coefficient between the worm and the worm wheel. Moreover in some special cases, the worm gear can become self-locking mechanism, this phenomena takes place when the lead angle is smaller than the apparent friction angle.

2.2 Worm gear: self-locking

Dr. A.L. Kapelevich, AK Gears, LLC and Dr. E. Taye, ET Analytical Engineering, LLC studied in their paper In most of the gear drives, when the driving torque is suddenly reduced as a result of power off, torsional vibration, power outage or any mechanical failure at the transmission input side, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as back driving. During inertial motion or back driving, the driven output shaft (load) becomes the driving one and the driving input shaft (load) becomes the driven one. There are many gear drive applications where the output shaft driving is less desirable. In order to prevent it, different types of brake or clutch devices are used. However, there are also solutions in gear transmission that prevent inertial motion or back driving using self-locking gears without any additional devices. The most common one is a worm gear with a low lead angle. In self-locking worm gears, torque applied from the load side (worm gear) is blocked, i.e. cannot drive the worm. However, their application comes with some limitations: the crossed axis shafts' arrangement, relatively high gear ratio, low speed, low gear mesh efficiency, increased heat generation, etc. The paper describes the design approach as well as potential applications of the parallel axis self-locking gears. These gears, unlike the worm gears don't have such application limitations. They can utilize any gear ratio from 1:1 and higher. They can be external, internal, or incorporated into the planetary gear stage or multistage gear system. Their gear mesh efficiency is significantly higher than the worm gears and closer to conventional gears. As a result they generate less heat. The self-locking can be designed to prevent either the inertia driving, or back driving, or both. The paper explains the principle of the self-locking process for gears with symmetric and asymmetric teeth profile, and shows their suitability for different applications. It defines the main parameters of gear geometry and operating conditions. It also describes potential self-locking gear applications and references to related publications.

2.3 Self-locking principle: Applications

Alex Kapelevich and Elias taye, Applications for Self-locking Gears (May 2012), Studied about application of self-locking gears that self-locking gears prevent back driving and inertial driving ,and they may find applications in a wide variety of industries. They mainly worked on finding self-locking conditions, also compare conventional and self-locking gears. They designed self-locking helical and fouble helical gears. During testing of self-locking gears they found an integrated speed and torque sensor was mounted on the high-speed shaft of the gearbox and Hysteresis Brake Dynamometer (HD) was connected to the low speed shaft of the gearbox via coupling. The input and output torque and speed information were captured in the data acquisition tool and further analysed in a computer using data analysis software. The instantaneous efficiency of the actuator was calculated and plotted for a wide range of speed/torque combination. Average driving efficiency of the self-locking gear obtained during testing was above 85 percent. The self-locking property of the helical gear set in back driving mode was also tested. During this test the external torque was applied to the output gear shaft and the angular transducer showed no angular movement of input shaft, which confirmed the self-locking condition.

In this paper, a principle of work of the self-locking gears has been described by author. Design specifics of the self-locking gears with symmetric and asymmetric profiles are shown and testing of the gear

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prototypes has proved relatively high driving efficiency and reliable self-locking. The self-locking gears may find many applications in various industries. For example, in a control systems where position stability is very important (such as in automotive, aerospace, medical, robotic, agricultural etc.) the self-locking will allow to achieve required performance. Similar to the worm self-locking gears, the parallel axis self-locking gears are sensitive to operating conditions. The locking reliability is affected by lubrication, vibration, misalignment, etc. Implementation of these gears should be done with caution and requires comprehensive testing in all possible operating conditions.

3. Worm gear self-locking in lifting application or winch system

3.1 Worm pair in manual clutch

Professor, Mechanical Engineering Department, S.I.T.S., Narhe, Pune, University of Pune, India in their paper, "Design and analysis of worm pair used in self-locking system with development of manual clutch" mainly studied about self-locking principle of worm gear. Mostly in material handling equipment gear drives are used. In these systems when the driving torque is suddenly decreased due to power off or any mechanical failure at the input shaft of the system, then gears will be rotating either in the same direction driven by the system inertia, or in the opposite direction driven by the resistant output load due to gravity, spring load, etc. The latter condition is known as back driving. However, there are also solutions in gear transmission that prevent inertial motion or back driving using self-locking gears without any additional devices.

Self-locking is the ability of gear system which constitute a drive which gives the input gear the freedom to rotate the output gear in either directions but the output gear locks with input when an outside torque attempts to rotate the output in either direction. Worm gear pair is also a self-locking gear pair but it is having very low efficiency around 40%, when made self-locking. In our project, self-locking property is obtained by using worm pair which is in mesh with each other. This system is simple in construction. The efficiency around 90% can be obtained as compared to 40% of conventional worm gear system. They provide some future scope, the present set up is manually operated, hence this limits the load carrying ability of the system, and within appropriate gearing we can increase the mechanical advantage thereby improving the load carrying ability. The present system has an open casing thereby the need of external lubrication may arise, with appropriate modifications we can make cast iron casing to retain the lubricating oil. By employing some improved processes and fine workmanship in manufacturing we can further achieve improved quality of parts and which may affect the results in positive manner.

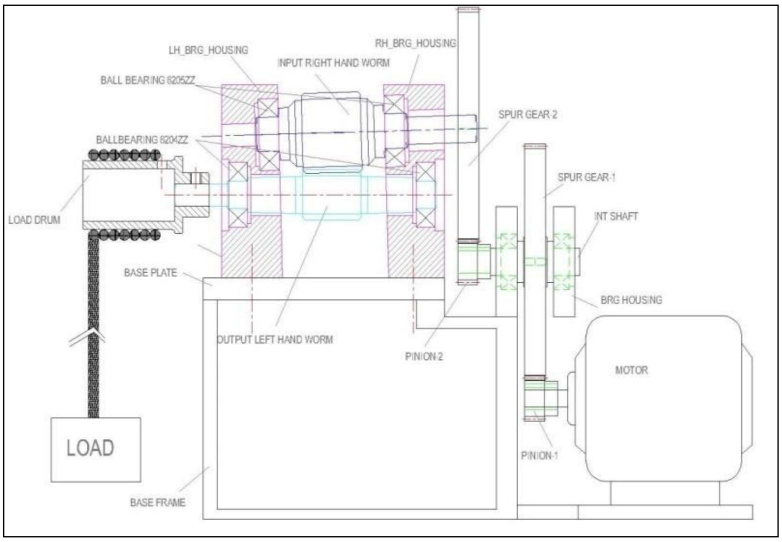

Fig: Worm pair system used in load lifting device

3.2 Limited force, self-locking tensioner

Bryan J. Stone, had invented a patent "limited force, self-locking tensioner", A tensioning device configured for use in a conveyor system as an idler roller over which a belt wound under tension include, an arm mounted in housing for liner moment in and out of housing a roller mechanism mounted at a distance including a roller configured for rolling contact with a belt of conveyor system and actuator for extending and retracting the arm from housing. The actuators include warm. Warm shaft and lead screws.

3.3 Open gears for winch drums

In several applications like hoisting equipment, cranes, open gears are used to transmit power at rather low speeds (tangential velocity < 1m/s) with lubrication by grease. In consequence those applications have particularities in term of lubricating conditions and friction involved, pairing of material between pinion and gear wheel, lubricant supply, loading cycles and behaviour of materials with significant contact pressure due to lower number of cycles. The comparison of proofed old rating methods (HENRIOT….) with ISO 6336 has shown that ISO is very conservative for through hardened steels gear wheels running with case hardened pinion specifically in the range of limited life.
This has emphasis the need to develop experimental tests, in representative conditions. In order to assess new values of allowable contact-pressure stress numbers, the authors present the concept and the realization of a new test bench in order to satisfy those requirements with the associated procedures of calibration and testing. Analysis of experimental results and metallurgical analysis of cold working of tooth flanks are given. Fatigue result test are then compared to ISO and AGMA gear ratting method predictions.
M. octrue, done test with various conditions such as with hydraulic system, air-grease spray systems with protector casing, without casing and lubrication system. Author found that this new testing rig allows investigating low speed open gear under various conditions like as running with grinding case, at low speed, with spray lubrication. So the load capacity of 42MnCrM04 is significantly improved.

4. Self-locking property

Large frictional forces cause most screws in practical use to be "self-locking", also called "non-reciprocal" or "non-overhauling". This means that applying a torque to the shaft will cause it to turn, but no amount of axial load force against the shaft will cause it to turn back the other way, even if the applied torque is zero. This is in contrast to some other simple machines which are "reciprocal" or "non locking" which means if the load force is great enough they will move backwards or "overhaul". Thus, the machine can be used in either direction. For example, in a lever, if the force on the load end is too large it will move backwards, doing work on the applied force. Most screws are designed to be self-locking, and in the absence of torque on the shaft will stay at whatever position they are left. However, some screw mechanisms with a large enough pitch and good lubrication are not self-locking and will overhaul, and a very few, such as a push drill, use the screw in this "backwards" sense, applying axial force to the shaft to turn the screw.

This self-locking property is one reason for the very large use of the screw in threaded fasteners such as wood screws, sheet metal screws, studs and bolts. Tightening the fastener by turning it puts compression force on the materials or parts being fastened together, but no amount of force from the parts will cause the screw to untighten. This property is also the basis for the use of screws in screw top container lids, vises, C-clamps, and screw jacks. A heavy object can be raised by turning the jack shaft, but when the shaft is released it will stay at whatever height it is raised to.A screw will be self-locking if and only if its efficiency $\eta$is below 50%.

Whether a screw is self-locking ultimately depends on the pitch angle and the coefficient of friction of the threads; very well-lubricated, low friction threads.

5. Conclusion

Thus we can conclude that the if worm gear drives when used for lifting applications with self-locking then primary objective for safety considerations the drives are extremely in-efficient. Hence there is a need of special purpose drive that will provide better transmission efficiency in self-locking condition and reduction in power consumption of the device and providing compactness to device...i.e. lowering the running cost of device.

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