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Review of Design and Optimization of "Mechanical Torque Booster"

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Abstract:-
This review article investigates the design, development, and optimization of mechanical torque boosters based on the capstan concept, in order to improve torque transmission through the frictional interaction between a rope and a drum,. Analysis of design processes, operating principles, material choices, and performance metrics including torque, speed, efficiency, and power amplification ratio are all prioritized. Prior research and prototypes show that amplification is highly dependent on a number of variables, such as the diameter of the drum, the rope material, and the coefficient of friction. This study identifies the gaps in existing research and shows potential to improve efficiency, dependability, and compactness by combining results from simulation-based methods, analytical models, and experimental studies. The study finds that although additional material and design parameter modification might greatly improve their performance, mechanical torque boosters provide an affordable and useful substitute for industrial applications needing strong torque amplification with little input effort.

***Keywords*- Power Amplification, Torque, Capstan principle, Coefficient of friction.**

INTRODUCTION:-

A system that increases the torque imparted to a load by use of a capstan, a revolving drum or cylindrical surface that a rope or cable is coiled around, is referred to as a mechanical torque booster employing the capstan concept. The torque imparted to the load may be greatly increased by using this technique, which takes use of the mechanical advantage produced by friction between the rope and the capstan's surface. Large machinery frequently needs to be operated in industrial settings with minimal mechanical input or effort. This requires a Mechanical Torque Booster; otherwise, a large amount of input effort, which is often impossible to create manually, will be required. Load positioning is another area where a great deal of work is required. The objective of the project is to build a mechanical power booster prototype in order. To show the device's usefulness and efficacy the mechanical power booster will be analyzed using Ansys Workbench 16.0, and its component parts will be designed, developed, and analyzed using UnigraphixNx. The prototype will be developed using 3-D printing and the fused deposition process. To evaluate the performance of the created device in Tests will be done to determine torque, speed, power, efficiency, and power amplification ratio. By tailoring the power amplifier to the number of rope turns, the project also aims to maximize power amplification. The mechanical torque booster is based on the capstan principle, which increases the number of rope rotations to increase power production. In order for the rope to move at the same speed as the drum, the capstan is typically utilized to provide enough friction between the rope and the drum. For most lifting and winching jobs, any slippage is desired. This type of capstan usage could be classified as static due to the static friction that exists between the rope and the capstan. Conversely, kinetic friction happens. The mechanism is considered dynamic when the rope slides around the drum. [1] [2] [3]

PROBLEM FORMULATION:-

This study's foundation was established by reviewing research articles, patents, and technical reports. The Mechanical Torque Booster, typically built with rope wound around a drum, requires a compact design and elastic rope. Its amplification of load at the rope's output end is influenced by the rope's tension, the coefficient of friction between the rope and drum material, and the number of turns. Cost reduction and compactness necessitate modifications to features such as the motor drive of the input driving system and the drum's diameter. A key advantage is the elimination of additional apparatus for controlled positioning and movement of large objects, like transducers or pneumatic valves. The project aims to construct and test a prototype of this power amplifier to evaluate its performance in its intended application, optimizing the design for assembly dimensions, material, and the number of rope turns.

WORKING PRINCIPLE:-

The capstan principle is the based on the friction between the rope and drum. The friction between the rope and drum increase the output is increases. [2] The mechanical amplifier is basically based on the capstan principle. At one end load is connected and other end is connected to the input. The drum is connected to the motor and due to that the friction is takes place between the rope and drum. The friction is making the additional forces according to the output direction. [4] The friction energy helps to pull the load beyond the capacity is called as capstan principle.

$$Tload = T\, hold^{e\emptyset}$$

The provided text defines key variables integral to mechanical principles, specifically concerning friction and force transmission within a capstan system. The symbol 'µ' denotes the coefficient of friction (COF), which characterizes the frictional interaction between the rope and the capstan materials. 'Tlaod' is defined as the realistic tension on the rope line, representing the actual applied load or force. 'Thold' signifies the force applied at the opposite side of the capstan, acting as a counteracting or anchoring force. Lastly, 'Ø' represents the total angle swept by all rope turns around the capstan, measured in radians, indicating the extent of the rope's winding. This set of variables is fundamental for calculating forces and tensions in applications involving capstans, where friction and wrapping angles play significant roles.(i.e., with one full turn of the angle)[9]

The primary function of a capstan is to generate sufficient friction between a rope and its drum, ensuring that both components move in unison without slippage. In most lifting and winching operations, the absence of rope slippage is a critical requirement. When a capstan operates with static friction between the rope and the drum, this scenario can be characterized as a static system. Conversely, if the rope undergoes sliding motion around the drum, kinetic friction comes into play, and the system is then classified as dynamic. [1]

APPLICATIONS OF THE CAPSTAN PRINCIPLE:

1. Winches: To raise or move big objects with a comparatively modest input force, a rope or cable is looped around a revolving drum using the capstan concept. [10]
2. Sailing: To manage sails, ropes, and anchors, winches in sailing employ the capstan concept. [10]
3. Hoisting and Lifting: The capstan's mechanical advantage allows for the application of higher torque with less effort while lifting big things.[5]
4. Marine and Industrial Systems: Systems based on capstans are employed in cable pulling, towing, and mooring lines where high loads require amplified torque.[5] [10]

WORKING & METHODOLOGY:-

The Torque Booster is a mechanical device characterized by a rapid response time, delivering instantaneous power through continuously rotating drums. In position-control applications, unlike pneumatic, hydraulic, and electrical systems which require transducers for energy form conversion, this system operates mechanically. The system utilizes the holding force on one side of a capstan arrangement to amplify and sustain a significantly larger loading force on the opposite side. Specifically designed as a power amplifier, it facilitates directional output and accurate angular positioning by linking Bands A and B to an input shaft and an output arm. Clockwise rotation of the input shaft initiates the process by tightening Band A and securing it to its corresponding drum. This action connects the load end of Band A to the output arm, thereby transmitting the clockwise rotation of the tail drum to the output shaft. Concurrently, Band B, having been de-energized, slides over its drum. When the input shaft ceases its clockwise rotation, the release of tension allows Band A to slip on its drum. Conversely, if the input shaft attempts to rotate excessively rapidly, the output arm intervenes to arrest this motion, simultaneously tightening Band B onto the counter-clockwise rotating drum. The input shaft's direction of movement is reciprocal to the motor's rotation of Drum-B in a counter-clockwise direction. [7]

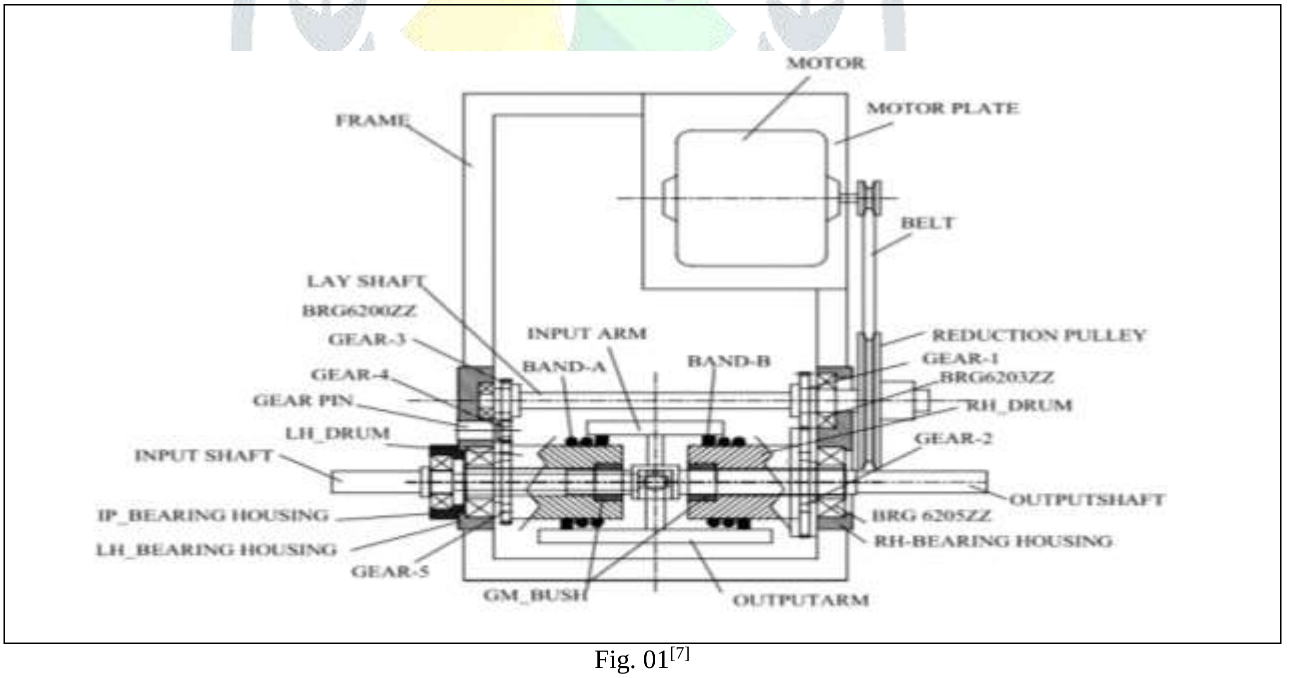

Fig. 01[7]

The input arm, powered by the input shaft, is linked to band A, which absorbs kinetic energy from a drum and multiplies it by the number of winding turns on the drum. This generated tension is then transmitted to band B, thereby increasing the load-carrying capacity and consequently delivering load to the output. The amplified torque is influenced by the drums' diameter, the number of wraps of the band on each drum, and the coefficient of friction between the band and the drum. Increased input power delivered to the input shaft is transmitted to the output shaft via the described amplifier architecture illustrated in Figure 01. [7]

MAIN COMPONENT OF THE MECHANISM-

The input shaft and the output shaft are integrally connected to the input arm and the output arm, respectively. These arms, in turn, are affixed at both their extremities to the bands that are meticulously wound onto the drums.

LH drum & RH drum: - The output shaft is equipped with bearings to support both the left and right drums independently. The band associated with these drums is routed around them and additionally secured to the input and output arms of the bearing housing. This band incorporates bearings at both of its extremities.[4] [9]

Frame:- The frame is identified as the primary structural element responsible for supporting the entire power amplifier assembly. This frame is specifically designed to integrate by welding with the motor plate and both the left-hand (LH) and right-hand (RH) bearing housings, thereby forming a unified and robust sub-assembly.[4] [9]

Friction band: - A 6-8 mm diameter rope, made of cotton, leather, and steel beads, functions as a friction band. This band is configured with one part coiled around the left drum and the other twisted around the right drum. The respective ends of these bands are secured to the input and output arms. [4] [9]

MATERIAL OF BAND OR ROPE:-

1. ***Lather:-*** Leather ropes or bands demonstrate a reduction in speed while concurrently increasing torque, load factor, and power amplification. However, they exhibit lower load-carrying capacity and reduced load-carrying stability compared to woven cotton. Despite these limitations, their power amplification capabilities surpass those of both cotton and steel ropes..[1] [5][7][9]
2. ***Woven Cotton:-*** The use of woven cotton rope in mechanical systems results in a reduction in speed. Concurrently, there is an increase in torque, the load factor, and power amplification. Furthermore, woven cotton rope demonstrates a greater load-carrying capacity compared to leather, and it also provides enhanced stability for load-bearing applications than leather.[1] [5][7][9]
3. ***Steel: -*** The steel rope demonstrates a higher efficiency compared to leather and cotton ropes. Specifically, while the steel rope experiences a reduction in speed, it exhibits an increase in torque, load factor, and power amplification. However, it possesses a lesser load-carrying capacity and reduced stability for load carrying when compared to woven cotton and leather. These observations are based on tests involving approximately three turns around a drum, with maximum loads ranging from 1000gm to 1200gm. The load-carrying capability is contingent upon the friction coefficient between the rope and the drum.. [1] [5][7][9]

GAP IDENTIFICATION:-

Sr. No.	Reference	Material Used	Result(Amplification Factor)
01	MECHANICAL POWER AMPLIFIER WORKING ON A CAPSTAN PRINCIPLE Thokale M. J. *Asst. Professor (Dept. Of Production Engg., AVCOE, Sangamner)*	Rope	Input Torque=0.33 Output Torque=2.02 P.A.F= 6
02	DESIGN AND DEVELOPMENT OF MECHANICAL POWER AMPLIFIER, V.R.Gambhire1, M.V.Mane2	No Mentioned	Only Showing ANSYS Report of Components.
03	Capstan Based Mechanical Power Amplifier Act as „Mechanical Torque Booster" 1C.D.Valunj, 2S.P.Mogal 1PG Student, 2Assistant Professor	Rope	P.A.F= 0.5
		Woven Cotton	P.A.F= 0.35
		Lather	P.A.F= 1.9

FEATURE SCOPE:-

The provided text analyzes power amplification factors derived from the utilization of steel, lather, and woven cotton. While a reference demonstrates the power amplification factor of these materials, it lacks specific details regarding the number of leather or rope spins, and consequently, no results are presented based on this omission. Furthermore, the design specifications for the components are not detailed. The first reference indicates that an input power of 9000 rpm is required to achieve a power amplification ratio of 6. In contrast, the third reference details an input speed of 850 rpm with a maximum applied load of 1000gm, yielding power amplification factors of 1.9 for lather, 0.35 for cotton, and 0.5 for rope. An observation from this data suggests that the power amplification factor diminishes as the motor's input speed escalates. The text reiterates the absence of discussion concerning design parameters.

ADVANTAGES:-

1. The capstan concept offers a method for achieving substantial torque multiplication without relying on conventional mechanical components such as gears or levers, thereby avoiding the bulk associated with such systems.
2. The provided text describes a system characterized by its versatility and simplicity, enabling an increase in torque through the use of basic components such as rope and a revolving drum.
3. The system's advantage of lower force requirements is detailed, explaining that it facilitates the management of large loads by enabling a significantly higher output torque to be produced with a reduced input force.

DISADVANTAGES:-

1. The text states that over time, both the rope and the capstan surface may require maintenance or replacement as a consequence of wear resulting from frictional force.
2. The torque boost mechanism might fail if the rope experiences slippage or lacks adequate friction.
3. The coefficient of friction, susceptible to external influences such as lubrication or moisture, imposes a restriction on the extent of amplification achievable.

CONCLUSION:

The capstan principle offers an effective and straightforward method for augmenting rotational force in numerous applications through the utilization of a mechanical torque booster. This system is engineered to manage significant loads and execute heavy lifting tasks with considerably reduced user force. Its operational mechanism allows for the doubling of input torque by capitalizing on friction and the mechanical advantage gained from the number of wraps a rope or band makes around a drum. Identified as a power amplifier or mechanical torque booster, this technique employs three wraps of materials such as leather, woven cotton, or steel rope/band around the drum to escalate the weight-bearing capacity by a factor ranging from 2.8 to three times. Additionally, the text establishes that an increase in the coefficient of friction directly correlates with a rise in the power amplification factor. [2] [4]

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