Development of a Wheel and Axle System Using a Resonating Spring for a Power Generation

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Abstract

A new technique is developed that provides an increment in torque without necessarily reducing speed. The increase in the torque and the ability of the machine to retain approximately the same speed means an increase in the mechanical power.

The consequence of this technology is vast application of low speed high torque machine to produce power using high speed running gear box system. It could also be useful to operate fuelless vessels that could be used to ply offshore waters.

The research has given a better insight that extra power can be injected into a mechanical system by a simple resonance of spring loadings. It is now known that energy can be sustained without much loss by the effect of spring resonance. This is a huge variation of the present state-of-the-art of using gear transmission systems.

1.0 Introduction

One of the challenges of power generation from renewable (except the nuclear technology) is the requirement of revolution per minute of the shaft-power and the associated torque. The inverse relation between shaft revolution per unit time and its associated torque makes relatively low energy sources unattractive for prime power systems. In Hydro Dams, the huge water mass and the potential height enable a huge torque that eventually develop sufficient speed for power generation. The huge costs and environmental challenges of Dam construction are well known.

Nigeria and most countries have huge river and ocean resource for instance [2]. The rivers flow with some energies and therefore some flow forces. Instead of operating a conventional gearing system at such low flow forces, the paper suggests a technique of multiplying the flow forces by some factors using simple wheel and axle principle in a novel manner.

The increasing energy demand of the country is well known. Water as a renewable energy source is readily available and represents a huge alternative to hydrocarbon energy with its associated green house-effect that is now threatening our world.

The unveiling of this system means that hydrokinetic energies of flowing waters etc can be harnessed and utilized. In most part of the Nigeria, according to the work of [1], huge energy can be sourced from rivers and this will unlock the potentials of local communities in generating power for the immediate use of the people instead of waiting for the grid power that may be epileptically available.

Effort multiplication capability of wheel and axle system has long been used in industries where small effort is required to operate relatively heavy load [3]. It is needful to reinvent this technique in a novel manner for power generation from upland rivers, streams and water flow systems, especially, where construction of dams may be uneconomical or environmentally challenging.

2.0 Methodology

The hypothesis in this work is that there exists a possibility to build a power transmission system that increases torque without equivalent reduction of angular revolution of the shaft. The consequence of this technique is an engineering technology that generates larger power than from the input power. Industry and literature reviews are carried out to provide basic theory for the hypothesis. The problem is a practical one and the approach chosen entails laboratory work, building and testing of prototypes to test the hypothesis.

Reviews indicated that input power cannot be more than the output power. This has been a fundamental understanding of engineering and science. In basic terms, it is expressed that energy or power cannot be created nor destroyed.

The understanding of physics of resonance from available literatures indicates that extra energy can be generated in springs especially in un-damped situations. This occurs because of coincidence of natural frequency of a loading structure and the induced frequency of the spring in motion. Even in damped conditions of springs (loaded situations in mechanical terms), there could still be some degree of amplification. It is based on this knowledge that the laboratory work is developed and planned to mimic the experience.

Within the laboratory work the following items were provided:

1. Spring of elasticity constant of 163 N/m
2. Weighing machine (range 0.00g to 5.00 kg)
3. Loading arm with a Torque weight (on output shaft)

A spring of elasticity constant of 163 N/m is suspended on spring supported frame (Figures 1 and 2). The Supporting frame is welded to a Base plate. A Crank link is connected to an axle on the output shaft of the machine. A Wheel is also connected to the shaft and the Output shaft is loaded with a perpendicular lever and loaded with a weight for Torgue measurement.

The input (effort) is provided either using a simple battery powered motor of 50 watts or manually provided using a spring balance. The later was used in this work and the common requirement is that the spring balance lifts the Moment Lever arm to a certain record of Force and it is then released suddenly. Should the 50watt dc motor be used, the Rise-Fall Cam will do the same function.

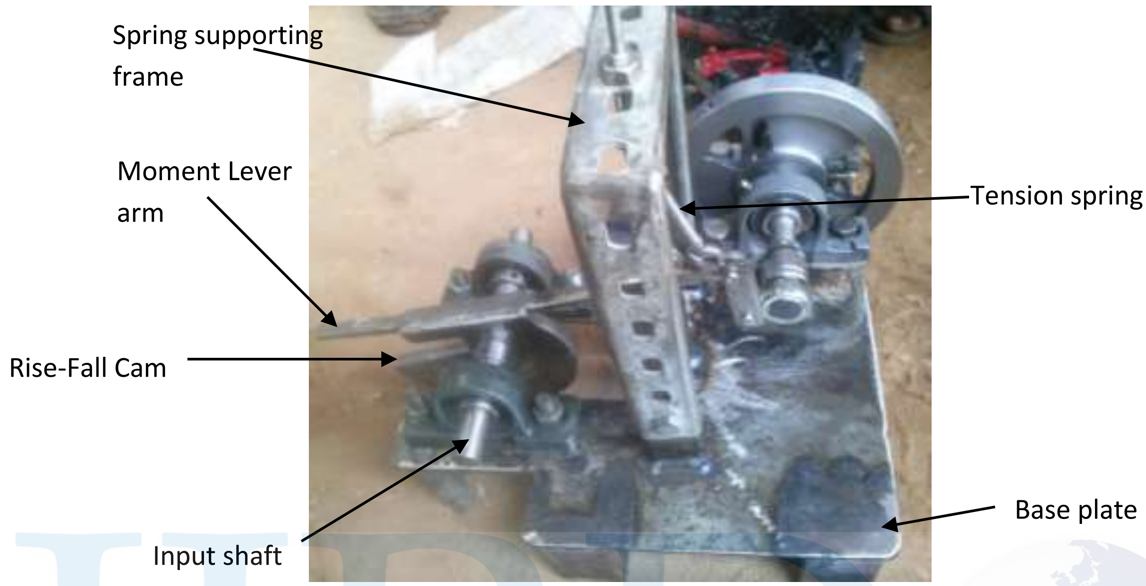

Figure 1: Testing of the concept

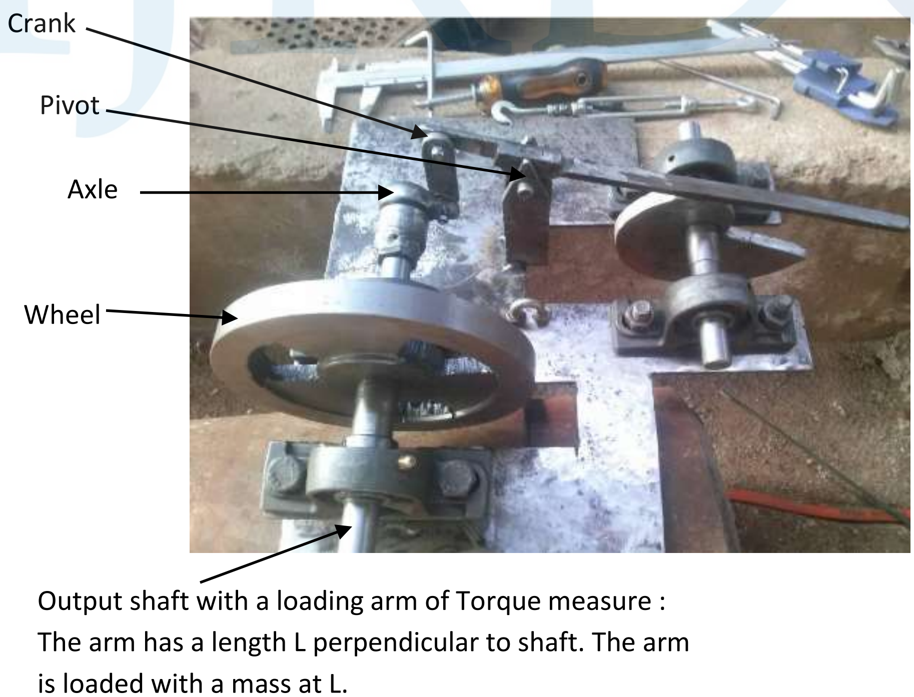

Figure 2: Testing of the concept (other view)

Let the simplified drawings of Figures 1 and 2 be given by Figures 3, 4, 5 and 6.

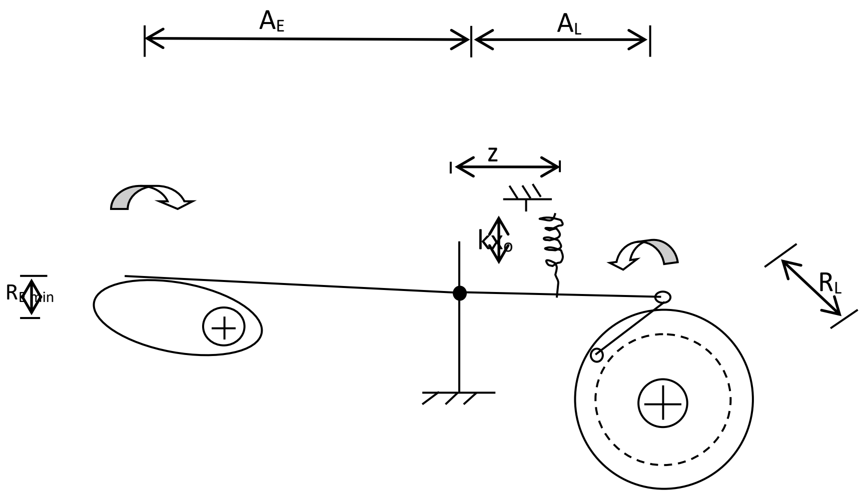

Figure 3: Initial position of machine's cam and spring

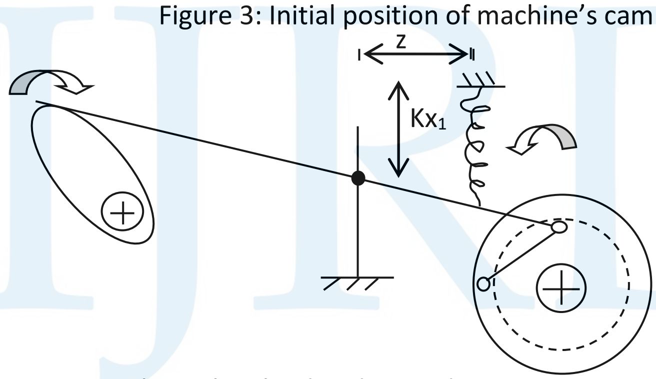

Figure 4: Cam has taken load and extending spring

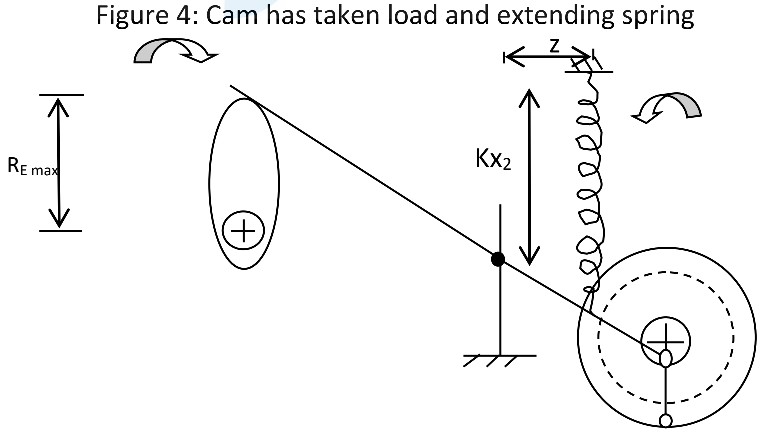

Figure 5: Cam has produced full extension of spring to X_2

In Moment terms at Figure 5,

$$A_E \times F_E = A_l \times F_l + kx_2 \times z \qquad (1)$$

Since the output shaft is on ratchet gear in which the load on anticlockwise is approximately zero,

$F_l \approx 0 \{Anticlockwise\ of\ ratchet\ gear\}$

$$F_E = \frac{kx_2 \times z}{A_E} \qquad (2)$$

$A_E = Effort\ arm\ length = 220mm$

$z = Spring\ arm\ length = 50mm$

$x_2 = Spring\ extension = 50mm$

$k = Spring\ constant = 163N/m$

$F_E = \frac{Kx_2 \times 0.05}{0.22} = 0.23\, Kx_2$ N

Or

$F_E = \frac{0.163 \times 0.05 \times 0.05}{0.22} = 0.0019$N

Output quantities will be calculated when the cam is suddenly displaced for sudden "pull back of the spring" as shown from Figure 5 to become Figure 6.

In Torque term,

Input Torque (max)= $F_E \times R_{E_{max}}$ (3)

Output Torque $= F_l{}' \times R_l$

$F_l' = Resolved\ force\ of\ the\ load\ in\ the\ vector\ of\ the\ link$ length R_l.

$F_l'\ is\ force\ generated\ on\ the\ link\ by\ the\ sudden\ return\ force\ of\ the\ spring\ to\ x_o$.

$F_l' \approx kx_2 = 0.163 \times 0.05 = 0.0082$ N

The result of the simulated F_l against F_l' is shown in Table 1.

Table 1: Simulated values of resolved F_l

F_l (N)	F_l1 (N)	F_l 2 (N)	F_l 3 (N)
100	92.758	92.901	92.84
500	463.876	464.21	464.201
1000	927.902	927.753	928.401
2000	1855.17	1855.45	1856.8
3000	2783.61	2782.77	2785.21

F_l 1(N), F_l 2 (N) and F_l3 (N) are the F_l' in different angles of the crank (0^0, 90^0 and 180^0).

Simulation was performed using SolidWork software.

The result indicates that:

$F_l' \approx F_l$

$R_{E_{max}} = 100mm$

$R_l = 25mm$

Input Torque (max) = $F_E \times 100mm = 100F_E$=0.00019 Nm or 0.023 Kx_2 Nm

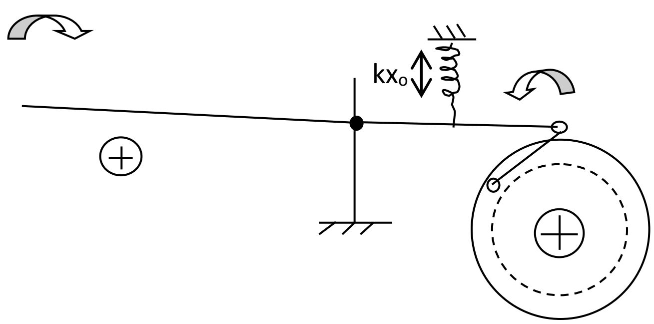

Figure 6: Cam slides off the lever, forcing the spring to return to suddenly to original X_o from extended X_2
.

Consider also a simple suddenly applied load system in dynamic terms as described in [4] and [5].

Taken that the cam is made to slide off the lever arm, the spring will quickly respond in shock to return the spring to its original position. This will certainly be the case provided that elastic limit of the spring is not exceeded during the extension to X_2. The scenario will be likened to the generalized diagram in Figure 7.

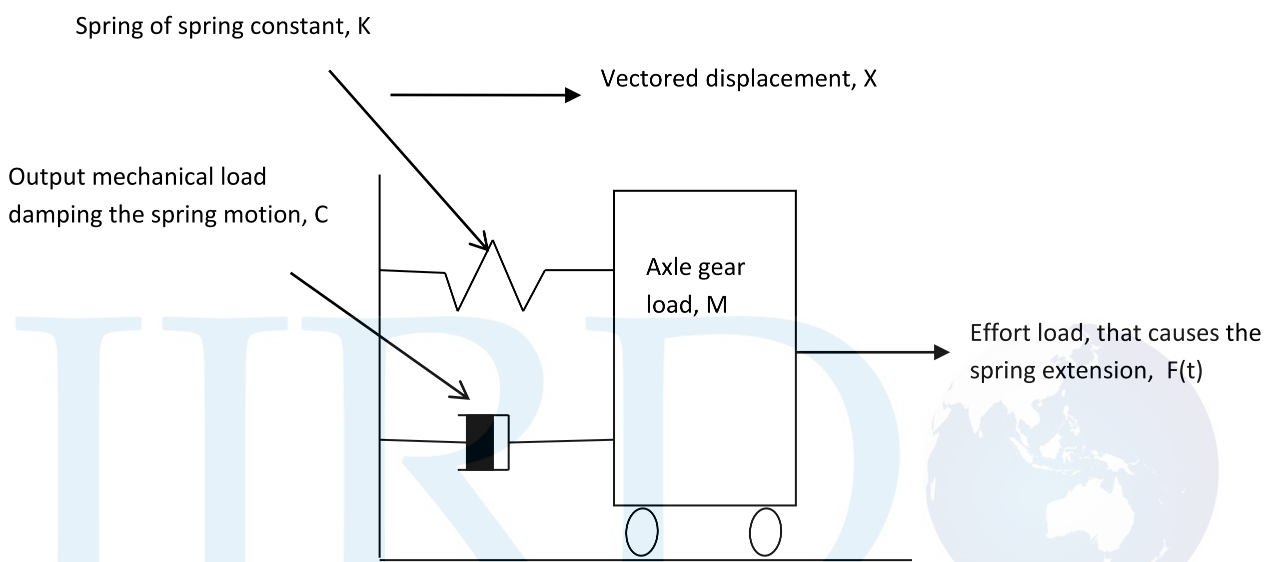

Figure 7: Idealized shock response and suddenly applied spring force

This will then introduce transient force analysis using classical dynamics. Use the primary consideration as the dynamic amplification. The basic elements of a dynamic system are mass, viscous damping and stiffness, idealized as a particle with mass, m, a linear spring with spring rate, k, and a dashpot with the damping coefficient C. The Figure 7 shows how damping is included but for most of this discussion. Summing forces on the mass provides the following:

$$\sum Fx = F(t) - kx - Cv = ma \qquad (4)$$

or

$$m\frac{d^2x}{d^2t} + c\frac{dx}{dt} + kx = F(t) \qquad (5)$$

The negative signs for the spring and damper forces follow because as shown, the spring and damper both oppose positive displacement.

If we take $\omega = \sqrt{\frac{k}{m}}$ $as\ the\ natural\ frequency\ of\ the\ spring$ in rad/sec and $\zeta = \frac{c}{2\sqrt{km}}$ $as\ the\ critical\ damping\ ratio\ of\ the\ damping\ pot$

Dividing through by the mass, m:

$$\frac{d^2x}{d^2t} + 2\zeta\omega\frac{dx}{dt} + \omega^2 x = F(t) \qquad (6)$$

The natural frequency determines the system stiffness–high frequency systems are considered 'stiff' irrespective of the individual values for k and m. The critical damping ratio defines whether the system is oscillatory. For most structures and machine elements the damping ratio is less than 10% ($\zeta < 0.1$) so they vibrate following a shock. On the other hand automobile suspensions (properly maintained) are highly damped so that striking a pothole does not produce oscillation and the critical damping ratio exceeds 1.

A solution of (6) according to [6] is

$$x = \frac{F}{K}\left[1 - e^{-\zeta\omega t}\left(Cos\ \omega t + \frac{\zeta}{\sqrt{1-\zeta^2}}\ Sin\ \omega t\right)\right]$$

The maximum displacement is

$$x_{max} = \frac{F}{K}\left(1 + e^{-\zeta\pi}\right)$$

$$Kx_{max} = F\left(1 + e^{-\zeta\pi}\right) \qquad (7)$$

$F = The\ force\ in\ the\ spring\ opposing\ F(t)\ in\ Figure\ 7$

$Note\ \ x_{max}\ occured\ due\ to\ \ force\ F(t)$

$$\left(1 + e^{-\zeta\pi}\right) = Amplification\ factor \quad (8)$$

Equation (7) suggests that force in the spring can be doubled for a case of zero damping. In our case, in this work, damping ratio is seldom known.

Re consider the problems of Figure 6.

Comparing,

$F_l'\ as\ the\ spring\ force\ is\ equivalent\ to$

$$F\left(1 + e^{-\zeta\pi}\right)$$

Output Torque $= F_l' \times R_l$ (9)

Since this is a sudden elastic load condition, the force could be doubled depending on the damping conditions of equation (7):

Output Torque $\approx\ 2(0.0082) \times 0.025$
$= 0.00041$ Nm

If N_E and N_L are shaft revolutions of input shaft and output shaft, the mechanism of Figures 3 to 6 indicate that $N_E = N_L$.

Power gain $P_g = \frac{2\pi \times Output\ Torque \times N_l}{2\pi \times Input\ Torque\ \times N_E} = \frac{2\pi \times 0.00041 \times N_l}{2\pi \times\ 0.00019 \times N_E} = 2.1$

This is the maximum possible expected gain of the system (when damping is ignored).

3.0 Result and Analysis:

Table 1: Result of the sudden arm release of Figure 1.

Driving load/g		Angular displacement=30deg=0.52rad		**Driven Load/g**		Angular displacement =15deg=0.25rad	
Mass/kg	Perpendicular arm/m	Equiv input torque/Nm	Work done/J	Mass/kg	Perpendicular arm/m	Equiv output torque/Nm	Workdone/J
0.52	0.08	0.41	0.212	0.42	0.032	0.13	0.033
0.16	0.16	0.25	0.131	0.309	0.07	0.21	0.053
0.11	0.16	0.17	0.090	0.42	0.07	0.29	0.072
0.083	0.16	0.13	0.068	0.568	0.07	0.39	0.098
0.08	0.16	0.13	0.065	0.624	0.07	0.43	0.107

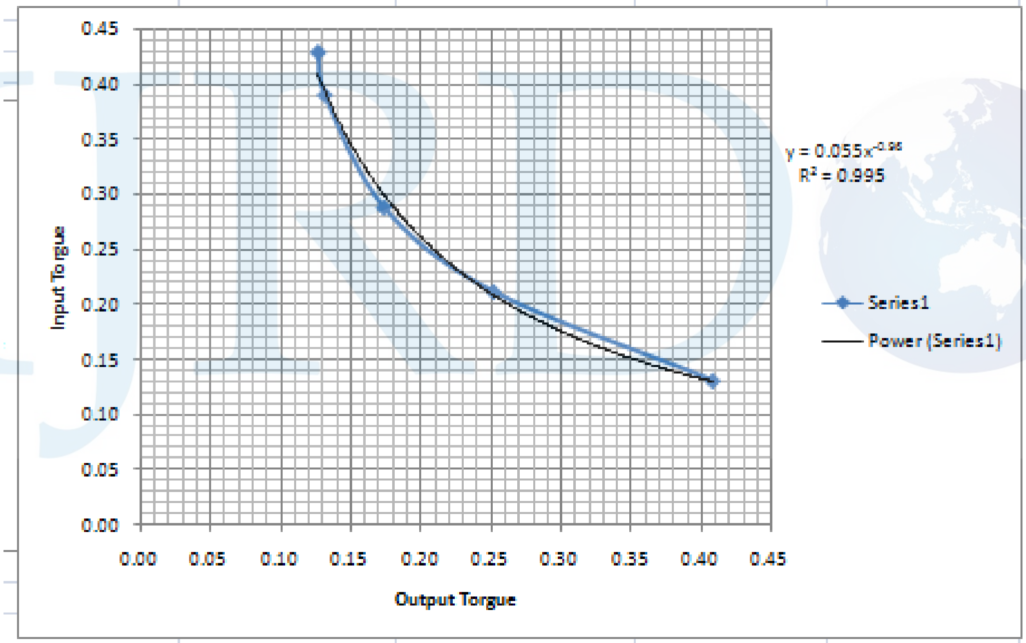

Figure 4: Graph characterizing input/output torques in Figure 1 tests

Power gain (empirical) at driven mass of 624g $= \frac{\text{Driven workdone per unit time}}{\text{Driving workdone per unit time}} = \frac{0.107}{0.065} = 1.6$

4.0 Conclusion

The hypothesis of this work has been tested in the laboratory. So far, it has turned out that it is possible to amplify Torque and with minimal equivalent reduction in speed, provided the spring is not fully damped on release and the Effort arm is considerable in length. To translate the laboratory outcome to solve engineering problem, the research has conceptualized a Spring-Lever Power Transmission System. This will be the same mechanism but linked in tandem. This technique is not only useful for the electricity generation but can be useful in the design of fuelless Offshore Vessels which is much needed in the offshore industry today. The application is also of great benefit to the automobile industry.

It hoped that this novel concept will be a game changer in the energy sector as mini power technologies can be raised into mega systems by the simple technology.

References:

[1] Agbakwuru A. J., 2017. "Sustainable Electricity Generation in Imo State Using Marine Power Technologies". Accepted for publication in the West African Journal of Industrial and Academic Research, Vol.18, No.1. 2017.

[2] Agbakwuru J.A. and Nwaoha T.C., 2015. "Energy Potential of West African Ocean Current - Peculiarities, Challenges and Perspectives". West African Journal of Industrial and Academic Research, Vol.15, No.1. December 2015.

[3] Shinkley J.E., Mischke C.R. and Brown T.H., 2004. "Standard Handbook of Machine Design, 3rd Edition, McGraw Hill.

[4] Harris, C. and Crede, C. Shock and Vibration Handbook, McGraw-Hill, New York, 1976.

[5] Timoshenko, S. P., Young, D.H. and Weaver, W. Vibration Problems in Engineering, Wiley, New York, 1974.

[6] Christopher, W.P.E. Introduction to Structural Impact. 2012. Retrieved from http://www.pdhonline.com/courses/s164

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