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Design and Development of Helical Compression Spring for Toggle Switch Mechanism

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Abstract**: India is well developed country for supplier of goods and services. Where efficient power supply system is the key ingredient for a country's economic growth and quality of lifes. Where current installed transmission capacity for evacuation is an emerging bottleneck, , distribution systems are outdated having huge losses are the cause of concern, so there is urgent need of up grading and enhancement of transmission and distribution infrastructure to empty requirement of additional power across countries. Most of the Switchgear industry continues to innovate and upgrade the products to achieve the future needs of its customer. Where the smart substation concept is built on state of the art automation technologies for substations, and should enable a more reliable and efficient protection, monitoring, control, operation and maintenance of the equipment and apparatus installed within the substations, as well as rapidly respond to system faults and provide increased operator safety. From this considerations we are developing spring for the Toggle switch mechanism which gives better results as compared to previous springs. For the same we are analyzing it by analytical, FEA as well as Experimental readings.**

In the FEA analysis modelling done by Pro-E software and analysis done by Ansys. This FEA analysis readings are compared with Experimental analysis. Which give good agreements in results. It also satisfies the industry requirements.

Keywords: Deflection, Regression, Spring, Strain Gauge, Stress

I. Introduction

This section will deal with the concept for an operating mechanism of earth switch.

A. Design of Conceptual 3D Model

Mathematical representation of any three-dimensional surface of an object is developed by 3D modelling. A conceptual model based on different technical and customer requirements is shown fig. As discussed in mechanical requirements of earth switch, we have considered the different geometry of components, appropriate material selection for mechanical component as spring for strengthening the assembly and electrical components for efficient current flow, spring and toggle mechanism design to have required high speed and reliability.

B. Conceptual Model of Operating Mechanism

This section studies the new possible configuration and evaluates their potential as new operating mechanism.

1. Component design

In this section, we will deal with the design of spring required to achieve the high velocity of moving blade and subsequently suitable for higher current rating applications in switchgears. All the components shall meet the different critical functional requirements.

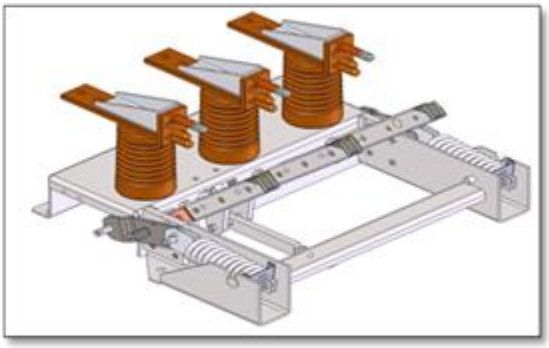

Fig. 1. Conceptual model of earth switch

The work presented in this paper focuses on design and analysis of earth switch Helical Compression Spring for higher system rating in the range of 25 kA to 40 kA. Present design is available up to 20kA. Considering market requirement, range of product is required to upgrade to 25kA, 31.5kA, 40 kA systems with improved functional reliability.

2. Helical spring

Helical springs are mostly intended for compressive or tensile load and are made up of wire coil in the form of a helix. Spring is made either o circular, square, or rectangular cross-section wire. Helical spring are of two forms compression helical spring as shown in Fig. 2, tension helical spring as shown in Fig. 2.

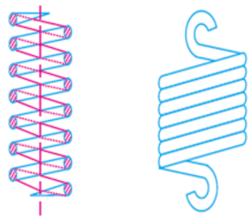

Fig. 2. Compression helical spring

Following important terms are used in connection with compression springs.

The ratio of mean diameter of the coil to the diameter of the wire is known as spring index. Mathematically,

Spring index, $C = D / d$

Where,

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D = Mean diameter of the coil
d = Diameter of the wire.

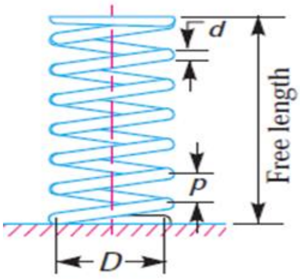

Fig. 3. Compression spring nomenclature

Experience has shown that value of C from 6 to 10 will result in a reasonable balanced design in relation to stability, size and efficient use of material.

Spring index, *C* = 6
D = Mean diameter of the coil = 50 mm
$C = D / d$
$6 = 50/d$
$d = 8.33$ *mm*

The spring is said to be solid when the compression spring is compressed until coil come in contact with each other. Solid length of compression spring is the product of total number of coils and the diameter of the wire. Mathematically,

$L_s = n'.d$
Where,
n' = Total number of coils
d = Diameter of the wire.
L_S = solid length = 100 mm
$L_S = n'.d$
$100 = n' \times 8.33$
n' =12.004
n' =12 Turns

The axial distance between adjacent coil in uncompressed state is the pitch of the coil. Mathematically, Pitch of the coil,

$$p = \frac{Free\ length}{n'-1} \tag{1}$$

Pitch of the coil can also be calculated by the following relation *i.e.* Pitch of the coil,

$$p = \frac{L_F - L_S}{n'-1} + d \tag{2}$$

Where,
L_F = Free length of the spring = 125 mm
L_S = Solid length of the spring = 100 mm
n' = Total number of coils = 12
d = Diameter of the wire = 8.33 mm

$$p = \frac{L_F - L_S}{n'-1} + d \tag{3}$$

$$p = \frac{125-100}{12-1} + 8.33 \tag{4}$$

$$p = 10.61\ mm.$$

TABLE I
DIMENSION DETAILS SPRING

S. No.	Element	Parameter	Value in mm
I	Spring	Mean diameter of the coil	50
		Diameter of the wire	8.4
		Total number of coils	12
		Pitch	10.61

TABLE II
MATERIAL PROPERTIES

S. No.	Properties	Properties
1	Elastic Modulus (E)	$2.05 * 10^5$Mpa
2	Poisson's Ratio	0.29
3	Tensile Ultimate strength	420Mpa
4	Tensile Yield strength	350 Mpa
5	Density	7870 kg/m3
6	Hardness	45 HRC
7	Hardness	45 HRC

II. LITERATURE REVIEW

Manan Deb et al. (2014) said the general information about the toggle switching. It is used in electrical switches of Mechanism. Where in this paper defines and classifies the toggle phenomena observed during switching. Concept of double toggle introduced in this paper enables a systematic screening of kinematic structure for the suitability in high performance switch. The Seven structural and three kinematic criteria are identified for this purpose. This is also demonstrated that each such feasible kinematic structure lends itself to multiple physical embodiment. Theory and procedure presented in this work can be used for design of numerous kinematic distinct mechanism. Representative of mechanical embodiment for a novel double toggle switch, including mass and geometric shape of links has been included in the paper. Electrical switch are mechanical interface to an electrical system which enables closing and opening of the circuit through the user input. Electric switch can be as simple as a knife switch where a conducting pivoted lever is directly manipulated using an insulating knob by the operator to make or break a circuit. The fixed contact is typically U-shaped which also acts as a clip to hold the lever in position when the circuit is closed. A switch there is a link for user input, called the handle which moves a current carrying member (follower) to make a specific region on it called moving contact, come in contact with another specific region on a fixed link called fixed contact. These contacts are made of special geometry and material suitable for good electrical performance under repeated impacts during making and breaking of the circuit. In this developments indicate use of an external spring to maintain the position of the handle in one of the two states, ON and OFF. Where the moving contact here was mounted on an elastic strip

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(beam) it was deformed by the actuation lever to establish contact.

Manan Deb et al. (2014) said about a special multi-degree of freedom toggle behaviour called double toggle mechanism. This paper identified and characterized a special multi-degree of freedom toggle behaviour, called double toggle, observed in a typical MCCB switching mechanisms. An idealized system, the condition of toggle sequence is derived geometrically. The existing tools available in a multi-body dynamics package are used for exploring the dynamic behaviour of such systems parametrically. Double toggle mechanism is found to make the system insensitive to the operator's behaviour the system is vulnerable under extreme usage. The linkage kinematics and stopper locations are found to have dominant role on the behaviour of the system. Which is revealed that the operating time is immune to the inertial property of the input link and sensitive to that of the output link. Designs exploiting this observation, in terms of spring and toggle placements, to enhance switching performance have also been reported in the paper.

Predrag Bojic et al. (2013) addresses the study of a high-speed earthing switch in gas-insulated metal enclosed switchgears. The high-speed earthing switch (HSES) are permanently installed switching apparatus in gas-insulated metal enclosed switchgear. The spring drive driven HSES has been developed and tested in one-phase and three-phase synthetic test circuits. Where HSES rated voltages of 245 kV and 300 kV, enable to perform closing (making) operation on the peak value of short circuit current of 20 kA without needing maintenance. This paper presents the main task of an HSES at application in GIS, design characteristics, and two different test procedure. Searching throughout standards was made in order to define the real status of this apparatus. Where Earthing switches are used for properly connecting de-energized live parts of the high voltage system to the grounding system. The outgoing side of the feeders, a make-proof version (high-speed) is frequently used to dissipate inductive and capacitive currents from parallel cables or overhead lines or to reduce the risk to the GIS system in case of faulty connections.

Rong-Fong Fung et al. (2011) studied motion of control of a toggle mechanism actuated by an electro hydraulic systems. Where control system is non-linear and time varying one due to the internal leakage of electro hydraulic system as well as the non-linear dynamic of toggle mechanisms. Specified position-velocity profile of the output slider of the toggle mechanism is considered as the desired trajectory.

Ravikant et al. (2013) has given the general information about the objective of the drive shaft. Drive shaft is connected with the transmission shaft with the help of universal joint. FEA of a drive shaft has been taken as a case study. Modal analysis of a drive shaft has been carried out the inherent frequencies and vibration mode shapes with their respective deformations. Maximum stress point and dangerous areas are found by the deformation analysis of drive shafts. The relationship between the frequency and the vibration modal is explained by the modal analysis of drive shaft.

This section deals with the review of past research done by researchers. This gives the information about the general requirement, functional requirement and details of testing for performance evaluation.

III. VELOCITY AND FORCE ANALYSIS

Given data from the model:

Crank = OA = 55 mm.
Connector = AB = 660 mm.
End plate = BD = ED = 60 mm.
Spring guide = EF = 182 mm.
Scale = 1:1
KV = 1

A. Velocity in Link

The Fig. 4, shows the configuration diagram of operating mechanism and fig. shows the velocity diagram of operating mechanism.

Consider,

a) Noa = crank speed= 10 rpm.

b) Angular velocity of crank Woa:

$$Woa = \frac{2\times\pi\times n}{60} \quad (5)$$

$$= \frac{2\times\pi\times 10}{60}$$

$$Woa = 1.05 \text{ Rad/sec.}$$

c) Velocity of crank OA:

$$Voa = Woa \times OA \quad (6)$$
$$= 1.05 \times 55$$
$$Voa = 57.57 \text{ mm/sec.}$$

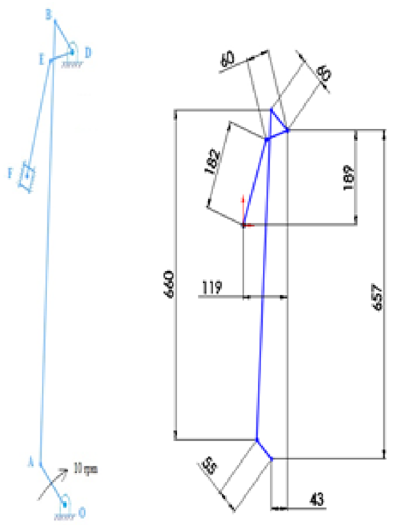

Fig. 4. Configuration diagram of operating mechanism

d) Velocity of Link plate OB:

$$Vob = KV \times OB \quad (7)$$

$= 1 \times 57.08$

$Vob = 57.08$ mm/sec.

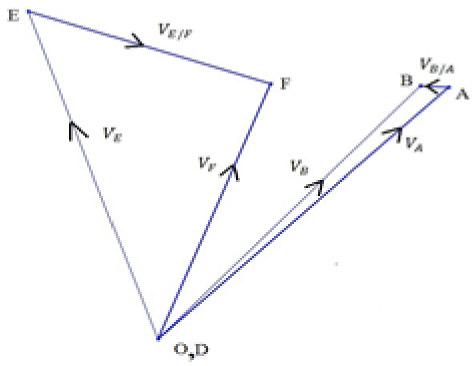

Fig. 5. Velocity diagram of operating mechanism

e) Velocity of Link plate w.r.t crank:

$$Vb/a = KV \times AB \tag{8}$$
$$= 1 \times 0.77$$
$$\frac{Vb}{a} = 0.77 \text{ mm/sec.}$$

f) Velocity of Link plate OE:

$$Voe = KV \times OE \tag{9}$$
$$= 1 \times 57.08$$
$$Voe = 57.08 \text{ mm/sec.}$$

g) Velocity of slider OF:

$$Vf = KV \times OF \tag{10}$$
$$= 1 \times 44.98$$
$$Vf = 44.98 \text{ mm/sec.}$$

h) Velocity of slider w.r.t link plate OE:

$$Ve/f = KV \times EF \tag{11}$$
$$= 1 \times 35.14$$
$$Ve/f = 35.14 \text{ mm/sec.}$$

i) Velocity of Components V_a, V_b, V_e And V_f in m/Sec:

TABLE III
VECTOR ANALYSIS

S. No.	V_a m/sec	V_b (m/sec)	V_e (m/sec)	V_f (m/sec)
1	0.058	0.057	0.057	0.045
2	0.23	0.228	0.23	0.18
3	0.46	0.457	0.46	0.36
4	5.76	5.708	5.71	4.498
5	28.78	28.54	28.54	22.48
6	29.36	29.11	29.11	22.938
7	32.24	31.97	31.97	25.187
8	33.39	33.10	33.10	26.087
9	35.98	35.67	35.67	28.11

i) Forces in Link

Any motion in a curved path represents accelerated motion and requires a force directed toward the centre of curvature of the path. This force is called the centripetal force.

$$F = \frac{m \times v^2}{r} \tag{12}$$

a) Force acting on crank OA:

$$Foa = \frac{m \times v^2}{r} \tag{13}$$

Where m = mass of crank OA = 0.13 kg (1.27N).

v = Voa = 0.058 m/sec.

r = length of crank OA = 0.055 m.

$$Foa = \frac{m \times v^2}{r} \tag{14}$$
$$= \frac{0.13 \times 0.058^2}{0.055}$$

$Foa = 0.0079$ N.

b) Force acting on link plate OB:

$$F_A \times Va = F_B \times Vb \tag{15}$$

$$F_B = \frac{F_A \times \text{Va}}{Vb} \tag{16}$$

$$= \frac{0.0079 \times 0.058}{0.057}$$

F_B = 0.0079 N.

c) Force acting on link plate OE:

$$F_E = F_B = 0.0079 \text{ N.}$$

d) Force acting on slider OF:

$$F_F \times Vf = F_E \times Ve \tag{17}$$

$$F_F = \frac{F_E \times \text{Ve}}{Vf} \tag{18}$$

$$F_F = \frac{0.0079 \times 0.057}{0.045}$$

F_F = 0.010 N

TABLE IV
FORCES ON LINK IN N

S. No.	F_a (N)	F_b (N)	F_e (N)	F_f (N)
1	0.0079	0.0079	0.007918	0.010048
2	0.16	0.13	0.126698	0.160784
3	0.50	0.51	0.506791	0.64312
4	78.51	79.19	79.18542	100.4878

IV. Analytical Analysis

W = axial load
D = mean coil diameter
d = diameter of spring wire
n = number of active coils
C = spring index = D / d for circular wires
l = length of spring wire
G = modulus of rigidity

A. Spring Index

$$C = \frac{50}{8.4} = 5.952 \tag{19}$$

Whalve stress factor,

$$K = \frac{4\,C-1}{4C-4} + \frac{0.615}{C} \tag{20}$$

Analytical Stress and Deflection sample calculation.

$$\tau = \frac{8*F*D}{3.142*\,d^3} \tag{21}$$

$$\tau = \frac{8*100.48*50}{3.142*\,9^3}$$

τ = 24.98608 Mpa.

$$\delta = \frac{8*F*\,D^3*n}{G*\,d^4} \tag{22}$$

$$\delta = \frac{8*100.48*\,50^3*n}{G*\,9^4}$$

$$\delta = \ 3.9783\ mm$$

TABLE V
Spring Analytical Solution

S. No.	Load	Stress	Deflection
1	0.01005	0.002499	0.0003979
2	0.16078	0.039978	0.0063653
3	0.64312	0.15991	0.0254614
4	100.488	24.98608	3.9783573
5	150	37.2971	5.9385557
6	200	49.72947	7.9180743
7	300	74.59421	11.877111
8	400	99.45894	15.836149
9	500	124.3237	19.795186

V. Finite Element Analysis

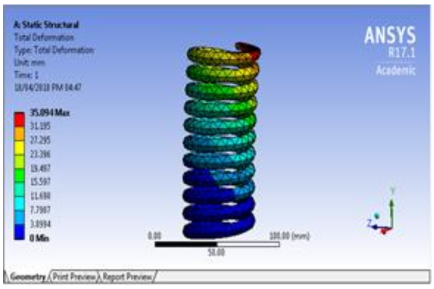

Fig. 6. FEA analysis of spring using Ansys

TABLE VI
FEA Analysis Reading for Spring

S. No.	Load	Stress	Deflection
1	0.01005	1.0369	0.068703
2	0.16078	2.0352	0.079255
3	0.64312	4.2562	0.113018
4	100.488	26.2354	7.102146
5	150	39.162	10.568
6	200	52.2159	14.068
7	300	78.3239	21.068
8	400	104.432	28.068
9	500	130.54	35.068

VI. Experimental Analysis

Experimental analysis consists of experimental setup for calculating various stresses developed on spring. Experimental setup consists of Universal Testing Machine, Strain guage indicator and strain gauges in order to determine the stresses developed on shaft. Mounting of strain gauge takes place on spring for the purpose of calculating stresses developed using strain gauge indicator.

Fig. 7. Strain gauge meter

Fig. 8. Experimental setup

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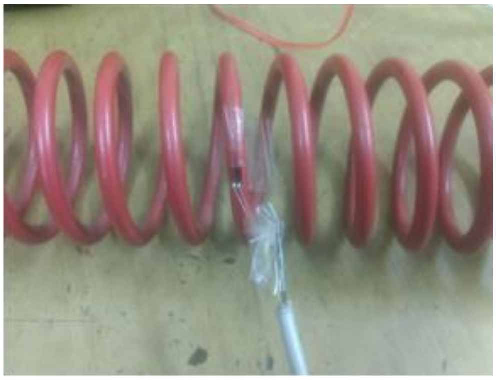

Fig. 9. Spring with strain gauge

Strain gauge with 350 ohm resistance is used for the experimental analysis. Strain gauge indicator is working on whinstone bridge principle.

TABLE VII
FEA ANALYSIS READING FOR SPRING

Observation	Load	Deformation	Maximum Stress
1	0.01005	0	1.11985
2	0.16078	0	2.19802
3	0.64312	0	4.5967
4	100.488	8	28.3342
5	150	11	42.2949
6	200	15	56.3932
7	300	23	84.5898
8	400	30	112.786
9	500	38	140.983

VII. RESULTS AND DISCUSSION

Spring is Design and manufacture in order to satisfy the requirement of application. Results are calculated through finite elements analysis using Ansys Software and are compared with Experimental Analysis. Forces developed during the operating mechanism are calculated using theory relative velocity method and are used for FEA analysis and Experimental analysis. Maximum Load acting on spring is 500 N. As gradually increasing load Stress and Deflection is Calculated and are in good agreement with experimental and FEA results. Strain gauges are used for calculating stresses developed in spring.

Regression Analysis:

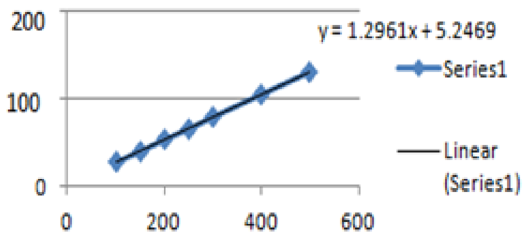

Fig. 10. According to Regression Analysis governing equation Spring load and stress is Y= 1.2961 X + 5.2459 For R^2 = 1 (Linear relation with load and Stress)

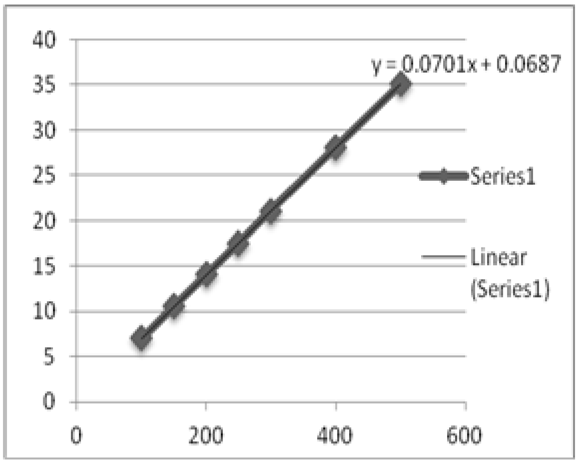

Fig. 11. According to Regression Analysis governing equation Spring load and deflection is Y= 0.070 X + 0.068 For R^2 = 1 (Linear relation with load and Stress)

According to Regression Analysis governing equation Spring load and stress is Y= 1.2961 X + 5.2459. According to Regression Analysis governing equation Spring load and deflection is Y= 0.070 X + 0.068.

VIII. CONCLUSION

Mentioned methodology can be used for design and development of various ratings of earth switch with overcoming different drawbacks of old designs. Selected toggle angle is suitable for given rating and force imparted for manual operation is quite less. It can be easily operated by human being.

Effective material selection for different components like mechanical structure, insulating material, material with high conductivity is very important aspect & improves functional ability of equipment.

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REFERENCES

[1] M. Deb and D. Sen, "Design of double toggle switching mechanisms", Mechanism and Machine Theory, vol. 71, pp. 163-190, 2014.
[2] M. Deb and D. Sen, "Parametric study of the behavior of double toggle switching mechanisms", Mechanism and Machine Theory, vol. 63, pp. 8-27, 2013.
[3] P. Bojic, "A high-speed earthing switch in gas-insulated metal enclosed switchgear", IEEE Transactions on Power Delivery, vol. 17, no. 1, pp. 117-122, 2002.
[4] R. Fung and R. Yang, "Motion control of an electrohydraulic actuated toggle mechanism", Mechatronics, vol. 11, no. 7, pp. 939-946, 2001.
[5] R. s, G. krishan and M. Didwania, "Modal analysis of drive shaft using FEA”", vol. 3, no. 1, pp. 4-7, 2013.
[6] S. Engleder, "Time-optimal motion planning and control of an electrohydraulically actuated toggle mechanism", Mechatronics, vol. 17, no. 8, pp. 448-456, 2007.

[7] T. Oiwa, N. Suzuki, K. Terabayashi and J. Asama, "High-speed and High-resolution Linear Microstepper Based on Toggle Mechanism Actuated by Electromagnet", The Proceedings of Mechanical Engineering Congress, Japan, vol. 2017, no. 0, p. S1140201, 2017.
[8] F. Lin, R. Fung and Y. Wang, "Sliding mode and fuzzy control of toggle mechanism using PM synchronous servomotor drive", IEE Proceedings - Control Theory and Applications, vol. 144, no. 5, pp. 393-402, 1997.
[9] A. Mostofi, "Toggle mechanisms: Dynamics and energy dissipation", Mechanism and Machine Theory, vol. 20, no. 2, pp. 83-93, 1985.
[10] P. Sharma, machine design, 4th ed. Kataria and Sons, 2012.
[11] S. Rattan, Theory of machines. New Delhi: McGraw-Hill Education (India) Private, 2014.
[12] J. Uicker, G. Pennock and J. Shigley, Theory of machines and mechanisms.