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Kinematic Analysis of Circuit Breaker Mechanism

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ABSTRACT

This paper presents the behavior of spring actuated medium voltage circuit breaker in opening and closing operations. Basic purpose of medium voltage circuit breaker is to operate system quickly to protect the components. The system consists of various linkages and springs, so the system is dynamically subjected to different forces and it can be analyzed by using simple kinematic analysis. The breaker consists of three springs closing spring, opening spring, contact spring the torque applied by this spring is calculated in the form of energy margin. Higher energy margin in system can cause damage to the parts while lower energy will cause half closing of breaker. So in initial development stage energy margin calculations are very much important. In this paper vector loop method is used to calculate angles and positions of linkages. The kinematic analysis shows that the average linear velocities in closing and opening operation are 1.17 m/s, 1.24 m/s respectively.

Keywords:— *Circuit Breaker, Energy Margin, Kinematic Analysis, Linear Velocity.*

I. INTRODUCTION

In the modern-day society, whether enterprise, agriculture, transportation or other fields, its miles tough to imagine that there is no the energy. In the manner of manufacturing and delivery of energy power, electricity distribution is a totally critical part. Medium voltage circuit breaker is a kind of electrical manage and protection gadget using inside the power distribution system.

Circuit breaker is an electric device used to protect system which is attached to transmission line with a help of circuit breaker. There are different types of circuit breaker available in a market, the classification is mostly base on voltage rating, installation location, external design and interrupting mechanism.

1.1 Main Components of Circuit Breaker

1. Interrupter: In circuit breaker contacts are enclosed in a steel chamber which is symmetrically attached to ceramic insulators. The contacts in interrupter are generally made up of cooper or aluminum because of their high conductivity. Interrupter consists of two contacts one is fixed contact and other one is moving contact which was actually a responsible to cut down electrical supply. The movement of moving contact is take place through the linkage mechanism. During the separation of contacts medium between these two contacts gets highly ionized and it glows in the form of arc. Current continuously flows between these contacts even though contacts are separated from each other. For total interruption of current path it is required to quench and extinguish arc as quickly as possible.

2. Support Insulator: These insulators are made up of epoxy resin material. The total length of insulators is depending on the Current and Voltage rating. Generally dielectric strength is the main concern in case of these systems so to fulfill dielectric parameters insulators with circular fin like appearance is used in the system this will lead to increases the Cree-page distance.

3. Connection Points: Connection points are the bus-bar connection points from these points input and output terminals are attached. Input terminals are attached to transmission grid-lines coming from power station while output connections are connected to low voltage transformer to distribute power to house, hospital, company, school etc.

4. Drive Box: Energy is required for the motion of moving contacts with respect to fixed contact. This energy needs to supply by certain set of mechanism which actuates the contact to open and close condition. Energy is provided in the form of spring energy, initially main spring also called as closing spring is stretch by motor and this energy is supply to main transmission shaft to close the contacts.

1.2 Problem Definition

During development stage of any circuit breaker it is essential to decide lengths and angle of various links. During initial stages stroke and velocity of moving contact is decided base on voltage rating. In this paper simple kinematic analysis is performed to trace the mechanism and to find rough average velocity of moving contact.

1.3 Methodology

Step by step procedure is followed to solve given problem,

Length of links and assembly positions are decided base on pervious breaker layout.

Springs selection and energy margin calculations are performed simultaneously, to check extra torque and proper energy balance in the system. In this step several trials are carried to select spring parameters

Simple line diagram is drawn in software with exact link dimensions, spring positions to find net torque supplied to the shaft by springs when shaft rotates through certain specified degrees.

II. ENERGY MARGIN CALCULATIONS

For working mechanism to be designed for circuit breaker, it should fulfill the conditions of torque balancing curve. To calculate the carried out torque from mechanism, it's far required to do. Here, the enter angular velocity isn't recognized. Subsequently, the test has been performed to get the angular speed of output shaft of running mechanism. So, angular speed of output link is understood. This will help to hold kinematic analysis of operating mechanism.

The circuit breaker consists of three types of springs namely Closing Spring (helps in closing operation), Opening Spring (charged by closing spring in closing operation and this store energy again use in opening operation), Contact Spring (charged by closing spring in closing operation used to held contacts in closed state).

As these all springs are attached with a shaft by various links. Initially the torque applied by all the springs on a shaft is calculated by using spring stiffness and spring deflection. System must have some extra torque to overcome the friction losses but higher extra torque may cause breakage of components so for proper energy margin limiting additional torque must 20-25% of closing torque.

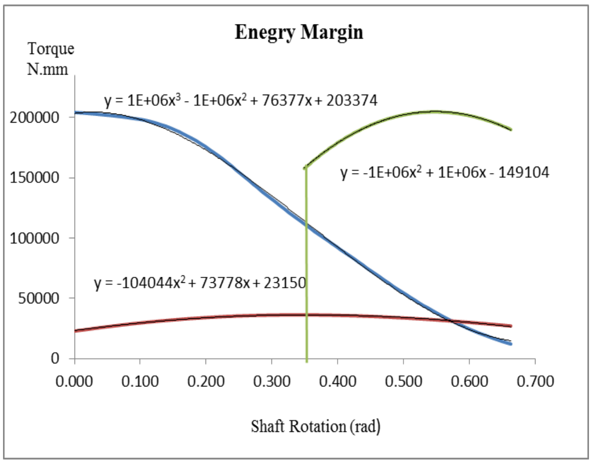


Figure 1. Energy Margin Curves

To find the net torque on shaft we need to take integration of the curve from lower to upper limits

1. Closing Curve (Blue Line)

$$y = \int_0^{0.663} (10^6 x^3 - 10^6 x^2 + 76377x + 203374)dx$$

= 102 J

2. Opening Curve (Red Line)

$$y = \int_0^{0.633} (-104044x^2 + 73778x + 23150)dx$$

= 21 J

3. Contact Curve (Blue Line)

$$y = \int_{0.349}^{0.663} (-10^6 x^2 + 10^6 x - 149104)dx$$

= 60 J

Extra Torque = Torque due to closing spring - Torque due to Opening spring - Torque due to contact spring.

III. Kinematic Analysis of Links

The vector-loop approach is an effective technique to research the kinematics of mechanism. Vector loop technique presents positional synthesis of mechanism below attention. Then by way of differentiating the positions with recognize to time velocities of every hyperlink are received. Further by differentiating speed equations, accelerations for each body is obtain.

Let θ, β and α are the angles of XY, YZ and WZ respectively measure along the fixed link WX. As in any configuration of the mechanism the figure must enclose. The links of mechanism can be considered as vectors. Thus the vector displacement relation can be derived as follows,

Displacement along X-axis

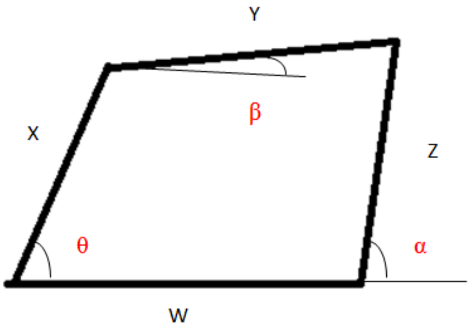
$$x\cos\theta + y\cos\beta = w + z\cos\alpha$$

$$(y\cos\beta)^2 = (w + z\cos\alpha - x\cos\theta)^2 \qquad \text{..........(1)}$$

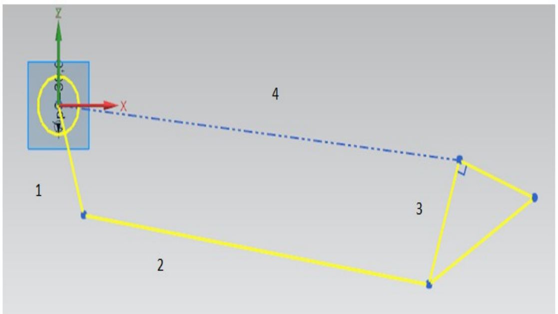
Displacement along Y-axis

$$x\sin\theta + y\sin\beta = z\sin\alpha$$

$$(y\sin\theta)^2 = (z\sin\alpha - x\sin\theta)^2 \qquad \text{.................(2)}$$



(a)



(b)

Figure 2. Basic Four Bar Chain (a), Circuit Breaker Linkage (b).

Adding equation 1 and 2 we get,

$$y^2 = x^2 + y^2 + w^2 - 2xz\cos\theta\cos\alpha$$

$$- 2xw\cos\theta + 2wz\cos\alpha - 2xz\sin\theta\sin\alpha \quad \ldots\ldots\ldots\ldots 3$$

Put,

$$x^2 - y^2 + z^2 + w^2 = 2k$$

As we know the following trigonometric relation,

$$\sin\alpha = \frac{2\tan\frac{\alpha}{2}}{1 + (\tan\frac{\alpha}{2})^2}$$

$$\cos\alpha = \frac{1 - (\tan\frac{\alpha}{2})^2}{1 + (\tan\frac{\alpha}{2})^2}$$

Equation (3) can be written as,

$$k - xz\cos\theta \times \frac{1-(\tan\frac{\alpha}{2})^2}{1+(\tan\frac{\alpha}{2})^2} - xw\cos\theta$$

$$+ wz \times \frac{1-(\tan\frac{\alpha}{2})^2}{1+(\tan\frac{\alpha}{2})^2} - xz\sin\theta \times \frac{2\tan\frac{\alpha}{2}}{1+(\tan\frac{\alpha}{2})^2} = 0$$

Multiple throughout by $1 + (\tan\frac{\alpha}{2})^2$
We get,

$$\tan\frac{\alpha}{2} = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

Where,

$$A = k - x(w - z)\cos\theta - zw$$

$$B = -2xz\sin\theta$$

$$C = k - x(z + w)\cos\theta + zw$$

Thus, the position of output link, given by an angle α, can be calculated if the magnitude of the links and position of input link are known i.e. x, y, z and θ are known.

A relation between the coupler link positions can be easily find out using equation (2)

$$x\sin\theta + y\sin\beta = z\sin\alpha$$

$$\sin\beta = \frac{z\sin\alpha - x\sin\theta}{y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Kinematic analysis of existing four bar mechanism is accomplished by following the vector loop method explained above. Kinematic analysis is useful in deciding interlock positions of shafts based on stroke length. Initial data required for kinematic analysis are crank angle, dimensions of shaft levers, rocker arm, and closing lever and stroke length. Initial procedure of existing mechanism is follow;

Configuration shown in figure 2b has following specifications,

- Crank lever length(X) = 45 mm
- Rocker arm length(Y) = 420 mm
- Input closing lever length (Z) = 85 mm
- Fixed link length (W) = 495 mm
- Initial crank lever angle (ϴ) =69.5 deg.

IV. Results And Discussion

Using above equation it is easy to trace the mechanism. Various performance parameters are listed below,

A. Angular Acceleration Calculation

Torque = Inertia × Angular acceleration

From cad geometry, it is easy find moment of inertia of shaft (0.311 kg.m^2)

B. Angular Velocity Calculations

Once the angular acceleration is find out it is easy to find respective angular velocity base on third equation of motion which is given below,

$$v^2 = u^2 + 2as \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This equation can be written as,

$$\omega_{12} = \sqrt{\omega_1 + 2\alpha\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

This equation is used to get the angular velocity at every position of an angle for link 1 or shaft. In above section the relation is established to find angular velocities of link 2 and 3 if angular velocity and angle of link1 is known to us. By using those relations we can easily find angular velocities of remaining two links.

C. Velocity of Output Link

The contacts are connected to lever in the form of slotted joint to allow the motion of contacts in straight line direction. Due to slot the length of arm changes every time with change in angle lever.

The velocity of link is given as,

$$V = r\omega$$

Where, r is the arm length

$$r = \frac{d}{\cos(\alpha - 90)} \quad \text{.....................................(7)}$$

d is the perpendicular distance between pivot joint of bell and contact joint.

In opening operation shaft is rotated by an angle of 20 degree. So initial angle is given as 0 degree. Table 2 shows the kinematical result of opening operation. In opening operation torque on shaft is due to opening spring discharge. In opening operation closing spring remains inactive.

Table 1 shown below shows the kinematical result of closing operation. In closing operation torque on shaft is equal to the difference between closing and opening spring torque.

Table 1. Closing Operation Calculation

Theta (Deg.)	Torque (Opening) N.mm	Torque (Closing) N.mm	Angular Acceleration Rad/ s^2	Angular Velocity (Link 1) Rad/s	Angular Velocity (Link 3) Rad/s	Angular Velocity (Link 2) Rad/s	Linear Velocity (Link 3) m/s
0.0	205980	27110	566.05	0.00	0.00	0.00	0.00
10.0	196663	34173	514.21	50.15	24.54	-3.87	1.35
20.0	132332	36540	303.14	89.04	48.09	-6.10	2.63

Table 2. Opening Operation Calculation

Theta (Deg.)	Torque (Opening) N.mm	Angular Acceleration Rad/s^2	Angular Velocity (Link 1) Rad/s	Angular Velocity (Link 3) Rad/s	Angular Velocity (Link 2) Rad/s	Linear Velocity (Link 3) m/s
20.0	36540	115.63	12.11	5.07	-1.04	-0.31
10.0	34173	108.14	50.55	24.86	-3.89	-1.42
0.0	27110	85.79	74.10	40.13	-5.05	-2.37

Table 3. Angle and Positions

Input Link Angle (θ)	Coupler Angle (β)`	Output Link Angle (α)	Stroke (mm)
69.5	4.6	104.1	0
64.5	5.0	101.4	3
59.5	5.4	98.5	5
54.5	5.8	96.5	7
49.5	6.2	94.3	11

D. Stroke of Output link

Using vector loop method, based on angle traversed by closing lever during closing operation, limiting angle of input crank lever can be calculated.

V. CONCLUSION

This paper presents the kinematic analysis of circuit breaker mechanism for finding desired performance parameters of circuit breaker like linear velocity, stroke etc., the mathematical calculations are performed. The maximum linear velocity of moving contact is found to be 2.63m/s in closing operation while -2.37 m/s in opening operation (the negative sign indicates the motion of contact in opposite direction). Generally for circuit breaker average velocity is important parameter than maximum velocity the values are 1.17 m/s and 1.24 m/s for closing and opening operation. The maximum distance travel by the moving contact is 11 mm, which was specified by the customers.

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