Application Brief

Lorentz Forces in Switches and Contacts

A disconnecting switch is a mechanical switching device that is normally closed, capable of carrying currents as well as opening or closing a circuit. Disconnecting switches are not meant to open live circuits but, rather, to disconnect apparatuses at the instant when they do not carry current. However, in large electric power systems operating at high voltages, disconnecting switches are sometimes forced open due to the magnetic repulsion caused by high short-circuit currents, which is not desirable. Determining this magnetic force helps designers to design switches that can withstand this force; in addition, it helps in creating circuits that produce the least force on the switches. Heavy-duty switches come with additional latches to withstand the force exerted on them and to keep them closed.

Another situation that requires the computation of electromagnetic force is contacts. The contact pair usually consists of a stationary contact and a spring-loaded moving contact. The mechanical spring force is much greater than the electromagnetic force under normal conditions. However, in circumstances in which large short-circuit currents arise, the latter surpasses the former force, resulting in the contacts separating from each other. This leads to arcing, which, in turn, causes erosion of the contacts. Knowing the force that separates the contacts helps engineers to design components that can withstand this force. Some applications that use butt contacts are vacuum interrupters and gas circuit breakers.

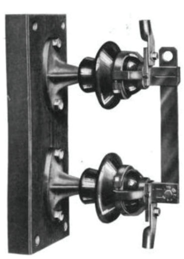

Figure 1. Simple disconnecting switch

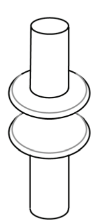

Figure 2. Simple butt contact

Products Used
ANSYS® Maxwell® 15.0.0 (3-D magnetostatic solver, 3-D parametrics, post-processing macros, field calculator)

Keywords
Disconnecting switch, contacts, electromagnetic force, Lorentz force, finite element modeling and analysis

Disconnecting Switch
A simple disconnecting switch comprises two round jaws of diameter D and a flat strap blade of width 2C. The mechanical force on the blade is proportional to the current in it as well as to the magnetic lines of force cutting through it. The direction of this force is perpendicular to the blade.

The formula for force at break jaw is derived in two cases: when $B < A$ and when $A < B$ [1].

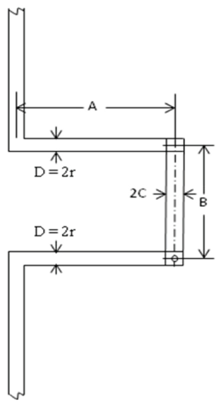

Figure 3. Simple disconnecting switch

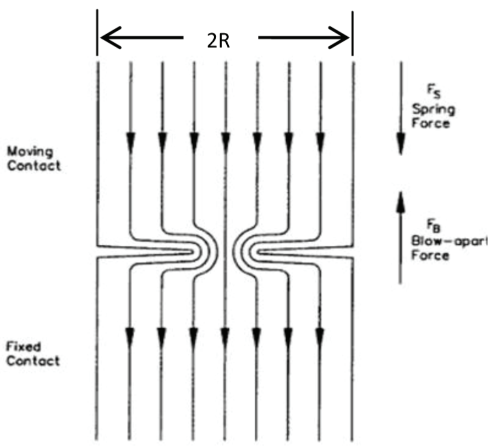

Figure 4. Touching rod contacts

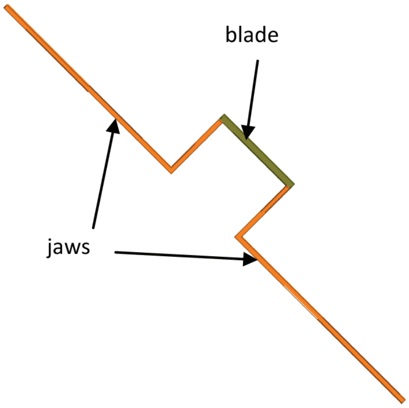

Figure 5. ANSYS Maxwell model of disconnecting switch

The magnetic force when B < A is given as:

$$\frac{I^2}{4.45\times 10^7}\left[2.30\log_{10}\left(\frac{B}{r}\right)+\frac{1}{3}-\frac{B}{A}+\frac{1}{4}\frac{B^2}{A^2}+\frac{3}{20}\frac{r^2}{A^2}-\frac{1}{32}\frac{B^4}{A^4}+\frac{B}{S}\right]\ pounds$$

When B < A, this force is expressed as:

$$\frac{I^2}{4.45\times 10^7}\left[2.30\log_{10}\left(\frac{2A}{r}\right)-\frac{2}{3}-\frac{1}{2}\frac{A}{B}-\frac{1}{6}\frac{C^2}{A^2}+\frac{3}{20}\frac{r^2}{A^2}+\frac{1}{24}\frac{A^2}{B^2}+\frac{1}{24}\frac{AC^2}{B^2}+\frac{B}{S}\right]\ pounds$$

As an example, the average force at the break jaw of a switch with A = 15 in, B = 20 in, 2C = 1.5 in, D = 1 in, at 30,000 A is calculated as 62 lbs.

Butt Contacts

The contact area between the butt contacts is only a fraction of the total area because of the microscopically rough surfaces as well as the fact that current actually flows only through the metallic joints that embed into each other when true contact is made. The magnetic repulsion force, or blow-off force, between the contacts is proportional to the square of current and is given as [2]:

$$F_B=\frac{\mu_0 I^2}{4\pi}\ln\frac{R}{a}$$

At the contact face, the spring force is given by the following equation:

$$F_S=\frac{\mu_0 I^2}{8\pi}\left(1+\ln\frac{8\pi HA}{\mu_0 I^2}\right)$$

in which A is the total area of the contact face.

When the blow-apart force and spring force are balanced (that is, $F_B=F_S$), then R/a = 86. For modeling in Maxwell, assume 1 inch round rods with R = 0.5 in and a = 0.0058 in.

Project Creation and Setup

The first step in the simulation is to set up the model using the 3-D magnetostatic solver in Maxwell.

To simplify the geometry of the disconnecting swtich, the jaws are assumed to be square instead of round. The model consists of four simple objects: two copper jaws carrying 30 kA current, a copper blade and a vacuum box enclosing these objects to allow for the fringing of flux. The thickness of the blade is assigned as a variable with a range from 0.1 in to 0.8 in to analyze its influence on the force at break jaw. The parameter torque is assigned on the blade with reference to the break jaw, the value of which can be read from the post-processor once the analysis is complete. An output variable is assigned to calculate the force at break jaw from the torque value (*F=T/radius*).

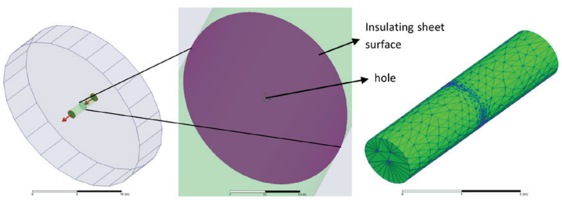

Figure 6. 3-D model of touching rod contacts in Maxwell

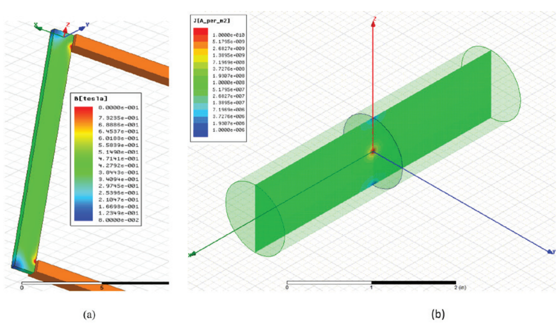

Figure 7. (a) Flux density distribution on blade of disconnecting switch; (b) current density distribution in cross-section of touching rod contacts

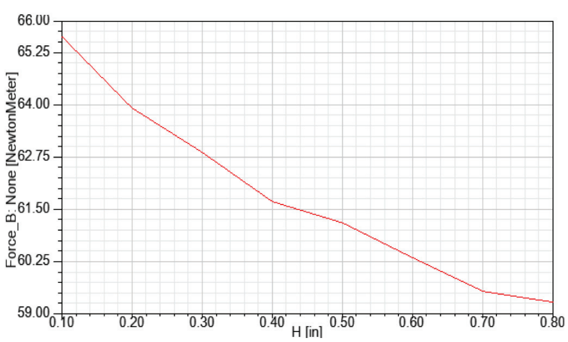

Figure 8. Variation of force with blade thickness of disconnecting switch

For the butt contacts, two round 1 in copper rods with a 0.0116 in hole (as an approximation for the arc) form the geometry of interest, which is surrounded by an air region to allocate the fringing flux. A variable is assigned for the current going into and out of copper rods, which varies from 20 kA to 200 kA in 10 linear steps. The arc is modeled as a hole with variable radius. An insulating sheet is assigned between the two touching rods. Length-based mesh operation is assigned on the insulating sheet that is the primary area of concern for accurate force calculation. However, Maxwell has the capability to automatically create the mesh and adaptively refine it at each adaptive pass. The output parameter force is assigned on one conductor, as the net force on both of them is zero.

Nominal Solution

The nominal project for the disconnecting switch is solved to 0.1 percent error and takes approximately 10 adaptive passes. The initial mesh consisted of 15,776 tetrahedrons, and the adaptively refined final mesh at tenth pass has 167,769 tetrahedrons. For the disconnecting switch example (assuming the blade thickness to be 0.4 in), the force at the break jaw as computed by Maxwell is 61.69 lbs, which is very close to the text book result (0.5 percent error).

The solution setup for the touching rod contacts project is set for 10 adaptive passes with 1 percent error and 0.001 nonlinear residual. Convergence is achieved in three passes with 0.039 percent error. The parametric solution is obtained in 10 minutes with approximately 1 minute for each current step and took less than 200M RAM.

Parametric Solution

A parametric analysis is carried out for the disconnecting switch by varying the thickness of the blade and computing the force at the break jaw for each thickness value. Figure 8 shows the plot of the force versus thickness.

Once the nominal project is solved for touching rod contacts, the final mesh can be re-used in a parametric solution, as there are no geometry changes. The Slade equation is entered in Maxwell using the field calculator tool to calculate the force (required to prevent blow off) as a function of current, conductor radius and arc radius. The geometry is analyzed for different current values in the contacts.

As seen in Table 1, the virtual and Lorentz force values obtained from Maxwell match well with that computed from the Slade equation.

Force vs Amps_1 — Maxwell3DDesign1

	amps [kA]	Force_lor.Force_x [kNewton] Setup1 : LastAdaptive	Force_vir.Force_x [kNewton] Setup1 : LastAdaptive	Slade formula Setup1 : LastAdaptive
1	20.000000	0.178702	0.178498	178.270007
2	40.000000	0.714810	0.713993	713.080029
3	60.000000	1.608322	1.606483	1604.430065
4	80.000000	2.856148	2.854841	2852.320116
5	100.000000	4.467560	4.462454	4456.750181
6	120.000000	6.426333	6.423392	6417.720260
7	140.000000	8.746954	8.742951	8735.230355
8	160.000000	11.424590	11.419360	11409.280463
9	180.000000	14.459250	14.452630	14439.870586
10	200.000000	17.850930	17.842760	17827.000723

Table 1. Force vs. current in touching rod contact obtained from ANSYS Maxwell (Lorentz, virtual) amd analytical formula by Slade

Summary

An area of concern for most electrical engineers who work with disconnectors and contacts is determining the electromagnetic force that sometimes causes them to open undesirably. ANSYS Maxwell software helps in calculating this force, allowing engineers to design switches that withstand the force. Further, parametric study can be conducted to evaluate the influence of design variables, such as thickness of a switch or current through contact on the electromagnetic force. The results obtained from Maxwell agree well with the published textbook results by H.B. Dwight and P. G. Slade.

Authors

Pavani Gottipati, pavani.gottipati@ansys.com
Mark Christini, mark.christini@ansys.com

References

[1] Dwight, H.B. *Electrical Coils and Conductors, Their Electrical Characteristics and Theory*. McGraw-Hill Book Company, Inc., 1945.

[2] Slade, P.G. *Electrical Contacts: Principles and Applications*. CRC Press, 1999.