Modeling of a Spring/Damper System for Electrical Contacts using Dynamic Designer in Autodesk Mechanical Desktop

Mary B. Groff
Advanced Technology & Analytics
Square D Company/Schneider Electric
Nashville, TN

ABSTRACT

Extreme space limitations and the desire to reduce the bounce between contacts prompted an investigation of the use of Belleville washers and Sorbothane as part of a spring/damper system in a medium voltage high-speed shorting device. Experimental tests in conjunction with mechanism simulation have been used to optimize a spring and damping system for the minimization of bounce that occurs during the closing of electrical contacts. Through the use of Dynamic Designer, the amount of stiffness and damping required, the identification of the optimum location of the damping system, and the mechanism components that were contributing to the bouncing phenomena were determined. The stiffness of the Belleville washers was tuned to the moving masses but the overtravel of the shaft was damped using a Sorbothane stack. This paper discusses the basic mechanism of a medium voltage switch and the modeling approach in Dynamic Designer. The experiments used for validation of the model are outlined. Correlation between the model and the test results conclude the paper.

INTRODUCTION

The use of mechansim simulation early in the design cycle is being implemented within Square D Company/Schneider Electric. In an effort to assess the value of using mechanism simulation within Autodesk Mechanical Desktop, an evaluation program was initiated during the concept and development of a medium voltage switchgear protection system. Dynamic Designer was used in the evaluation because of its seamless integration with Mechanical Desktop, thus reducing the learning curve required for its use in this pilot environment. Although this electrical protection system has multiple subsystems, only those components directly interfacing with the electrical contacts were used for this analysis.

The interruption and switching of current are key factors in the development of electrical distribution systems. Although the process of opening and closing a circuit appears to be very straightforward, the design of such a mechanism can be challenging. A system of springs is required to store the required energy needed to close the contacts quickly and to maintain sufficient force on the contacts to cause some of the surface discontinuities to be plastically deformed resulting in a larger area of actual contact. The contacts in this device exist within a vacuum bottle. The exceptional dielectric characteristics of a vacuum make this media particularly desirable for interruption in the medium voltage range (5 to 38 KV) of circuit breakers.

Generally, the modeling of circuit breakers and electrical power distribution switches requires a close integration with solid geometry to define the nature and locations of the impacts within the mechanisms. However, in this case, the location of the impact between the contacts is well defined and the geometry adds value as a means to illustrate the movement of the parts with relation to the adjoining parts. Figure 1 illustrates a typical configuration of the device for a single pole.

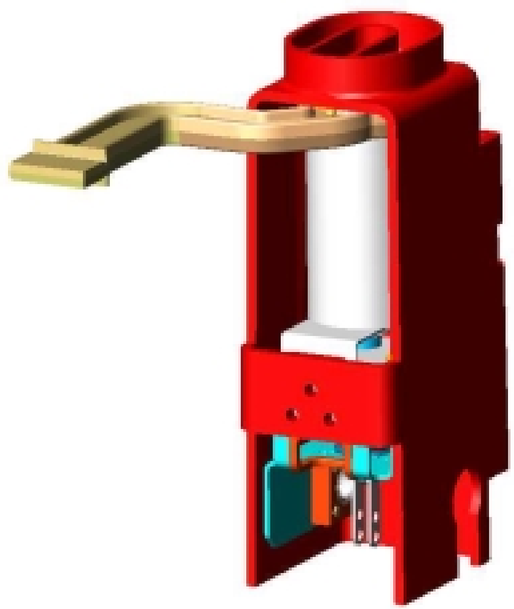

Figure 1 – 3-D Model of Medium Voltage Single Pole Protection Device

The analysis was initiated to assist in the design of the springs and dampers to reduce the bounce of the moveable contact on closing of the switch. Although the analysis could involve a truly multiphysical model, simplification was necessary to allow the analysis to be performed as a designer's tool and to provide information needed in the preliminary stages of design. The overall objective of the analysis was to verify the validity of using simplified models early in the design phase of projects.

SIMULATION MODEL

Description

The key use of Dynamic Designer in this application was the definition of the stiffness of the springs and the damping coefficient of the damper. The model was developed of only those components that were directly attached to either the moveable contact or the stationary contact. The stationary contact is stationary with respect to the vacuum bottle. However, the vacuum bottle itself does translate somewhat during the closing of the contacts. The stationary and moveable contacts are located within the vacuum bottle. In Figure 2, the bottom contact is the moving contact, which is attached to the lower current path through a stem and bellows to the connection block. The upper contact is the stationary contact, which is attached to the vacuum bottle. The vacuum bottle is rigidly attached to the bus bar through a series of Belleville washers. The Belleville washers act as a spring during the closing of the contacts. Of primary importance in the opening or closing of the contacts are the following factors.

- Opening and closing velocities
- Contact travel
- Bounce of contacts

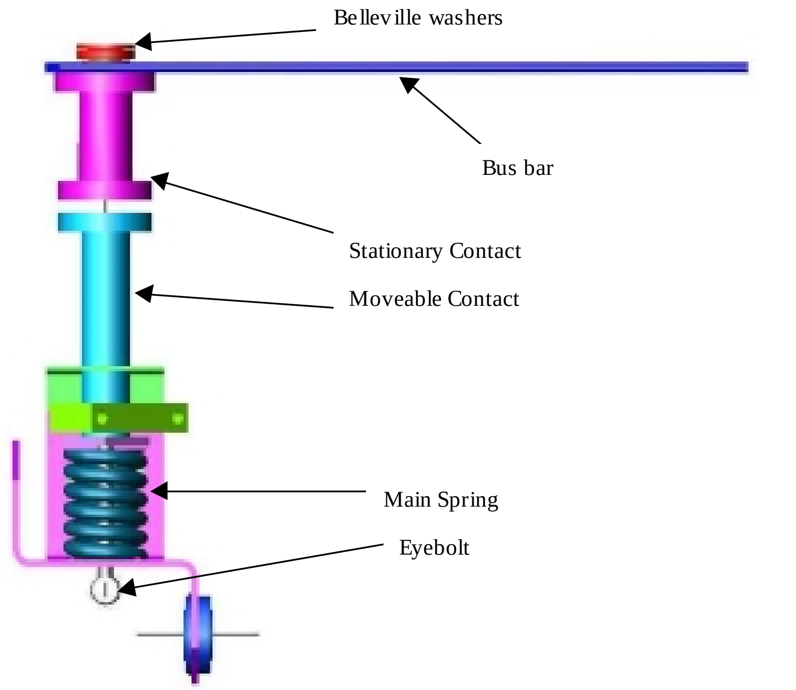

Figure 2 – Dynamic Model of Contacts

Of the many factors involved in the design, only two were evaluated using this simulation model. The first was the design of a spring to maintain the joint load on the bus bar that would fit in a very limited space allocation. The second issue was the damping of the contact bounce during closing of the contacts. Bounce in contacts is highly undesirable since welding of the contacts can occur during the recontact and separation operation.

Assumptions

The model assumes that the initial configuration as shown in Figure 2 is in the open and latched position. The main spring is charged and ready to release upon start of the simulation. The latching system for this switch is not included in this analysis. There is an additional force on the contacts due to the difference in pressure between the ambient and the vacuum interior of the switch. It was assumed that the transfer of constraints from the Mechanical Desktop assembly constraints to the ADAMS joint constraints produced a viable simulation model. It was assumed that redundant constraints were handled appropriately by the solver. There were a total of three degrees of freedom for the model.

The physical forces acting on the contacts in an electrical device include not only mechanical effects but also electrical and electomagnetic effects. The interaction of these forces is time dependent and also highly nonlinear. To maintain the scope of the model as one that can exist on a designer's workstation, it was necessary to make many simplifying assumptions. These assumptions have a tendency to make the validation of the model difficult. They require the overseeing engineer to use engineering judgement to be able to obtain valuable results from the simplified model. Experience in dealing with similar models indicates that, as a first look at the behavior, neglecting the electromagnetic forces is a reasonable assumption. Overall gross behavior can be represented without the inclusion of such effects as

- Constriction forces at, or near, first impact of the contacts,
- Current induced electromagnetic forces, and
- Plasma effects around the arcing between the contacts.

Springs

The space allotted for the spring to assist in controlling the bounce and to maintain adequate load on the joint was limited to 0.394 inches. The contact travel and the spring stiffness requirements led to the selection of a combination of Belleville washers to fulfill the spring requirements. Since Belleville washers, commonly called disc washers, can be combined in parallel and in series, a series of lab tests and virtual tests using this model were performed to determine the optimum configuration. Figure 3 illustrates the location of the Belleville washers.

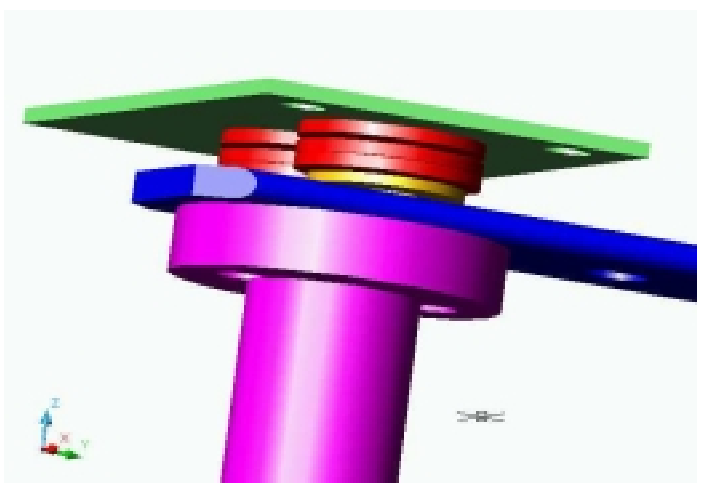

Figure 3 – Illustration of location and space allocation for Belleville washers

The stiffness of the Belleville spring washer is determined as follows.

$$r = \frac{Et}{(1-\sigma^2)Ma^2}\left[h^2 - 3\delta h + \left(\frac{3}{2}\delta^2 + t^2\right)\right]$$ [1]

where r = stiffness
E = Modulus of elasticity
t = thickness of the spring washer
σ = Poison's ratio
M = ratio of outer diameter to inner diameter
a = inner diameter
h = height of the washer
δ = amount of deflection of the washer

The total stiffness of Belleville washers in series can be calculated as follows:

$$K_{total} = \frac{1}{\frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3}}$$

where K_1, K_2, and K_3 are the individual disc spring stiffnesses.

The total stiffness of Belleville washers in parallel can be calculated as follows:

$$K_{total} = K_1 + K_2 + K_3$$

Using the average stiffness of the washer for the range of deflection and the summation of the washers, the stiffness of each set of Belleville washers was investigated. No damping is associated with these sets of washers. Testing of the washers indicates that there is essentially no damping associated with the use of Belleville washers in series. Limited damping can be see[2]n in disc washers in parallel but was neglected for this analysis.

Dampers

Damping for this system was investigated at both the stationary and the moveable contacts.

Pigtail force

The pigtail is a flexible connection between the moveable contact and a fixed bus bar. The pigtail consists of strands of copper wire twisted into a bundle. The pigtail is somewhat stiff installed and becomes stiffer upon application of current through the copper strands. The effect on contact closing, then, is much the same as a non-linear

[1] Almen, J. O. and László, A. The Uniform-Section Disk Spring. Trans. ASME 1936: **58**, 305-314.

spring. The stiffness of the pigtail spring was estimated based on test data taken during lab verification of the device.

RESULTS

The analysis consisted of a rather simple application involving only a few degrees of freedom. The results of the analysis and the ease at which the results were realized added value to the design process and reduced testing time that would have been required to test various configurations of springs and dampers. By eliminating configurations that were unlikely to produce desirable results, the test time was much more productive.

Springs

Since the linear travel of the disc washer spring assembly was known and the force required to maintain the integrity of the joint was known, it was found that two sets of three washers in series was optimum. The closing speed fell within the given guidelines.

Dampers

Initial testing of the device was done without the addition of a special damper. It is known that disc washers in series provide no damping to the system. Testing of the device indicated that the contacts bounced 2 to 3 times with the given configuration, Figure 4. Model data also indicated a multiple bounce situation, Figure 5. It was necessary, then, to determine the proper location for damping to be added to the system. High-speed video of the operation indicated that the optimum location for addition of a damper would be on the lower (per Figure 2) side of the device. This assumption was later validated with the model results. A sandwich structure using Sorbothane as a damping material was constructed. Estimates of the damping coefficient for this material were obtained from lab testing. The damper was added to the simulation model. Results from testing of the device with the Sorbothane sandwich damper are shown in Figure 7 with the associated model data shown in Figure 6.

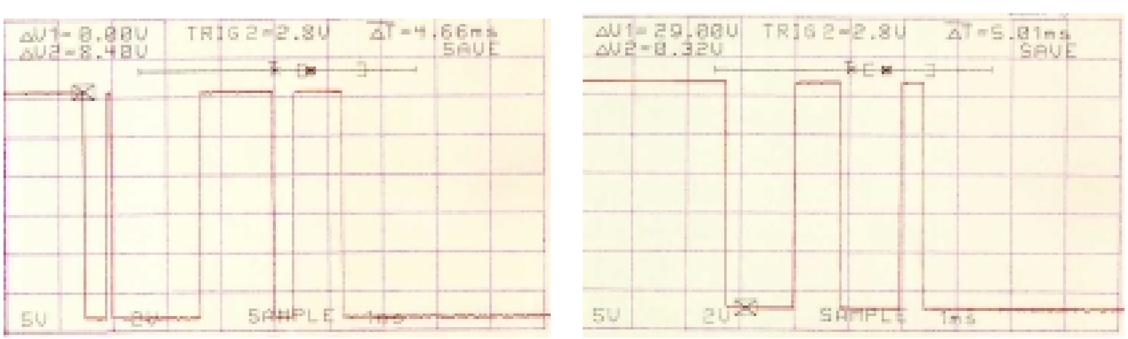

Figure 4 – Test data of the device without the damper

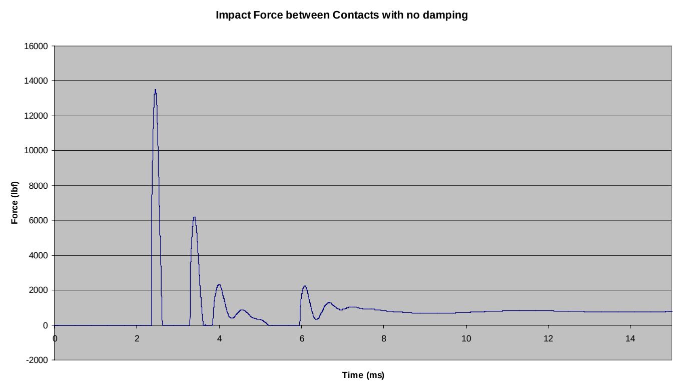

Figure 5 – Model results for the device without the damper

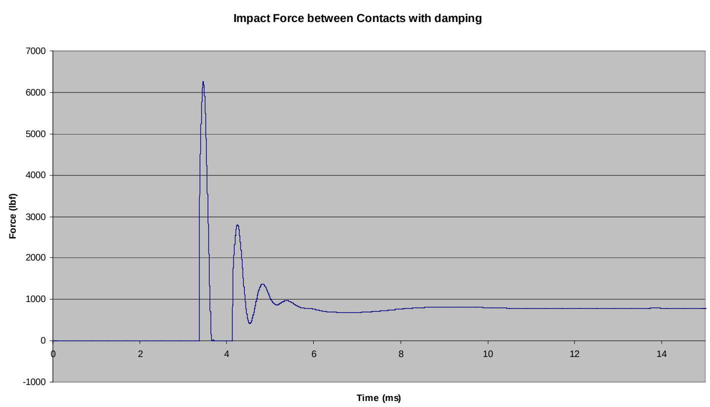

Figure 6 – Model data of the device with the damper

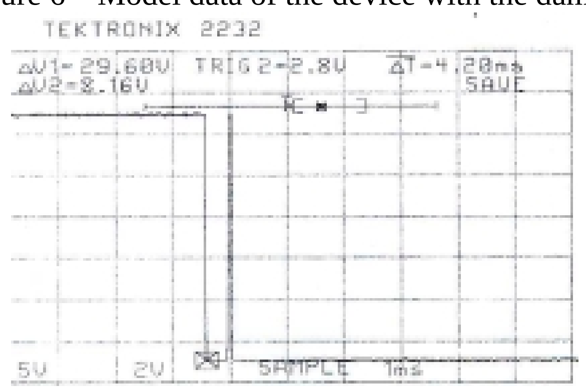

Figure 7 Test data of the device with the damper

Exact correlation of the bounce duration and the time between bounces has not been achieved. Taking into account the assumptions made in the development of the model, the results do indicate the overall behavior of the device and repeated testing indicates that the model holds up when the Belleville washer configuration has changed or the damper configuration has changed.

Pigtail

The addition of a spring to the moveable contact was able to account for some of the effects of the pigtail. It is recognized that this gross simplification was acceptable within the context of a first-look analysis. The addition of the pigtail effects proved to be an important part of the prediction of accurate time estimates. More work is required to characterize the actual non-linear behavior of the pigtail under high current.

CONCLUSIONS

The ability to perform quick look analyses reduced required lab verification time and added value and understanding of the physics involved in the contact closure phenomena. Issues for further study were identified. These included the effects of the pigtail on the closure time of the contacts, the effects of the actual contact flattening with operation time for contact closure, and the importance of the modeling procedure, from simple to complex. It is evident that by beginning with a simple model, the design team was able to focus on one issue at a time and develop a strategy for solving problems in a highly complex mechanism.

Virtual testing of the Belleville spring assembly allowed for the optimization of the spring configuration without the traditional lab testing time to verify each of the possible configurations. Bounce during closing of the contacts was reduced from a series of bounces to two.

An important conclusion of this analysis was the need for a more detailed analysis of all of the complex phenomena that occur during the activation of electrical switches and devices. It is clear that a coupled analysis of the mechanism simulation and electromagnetic effects is needed.

This paper illustrates the value of beginning with a simple model and expanding it to include more complex phenomena, as the physics of the mechanism are understood. The reduction of the number of bounces between the contacts was significant during the design of the device. Additional work on this model has been completed through the transference of this model to ADAMS.

BIBLIOGRAPHY

Almen, J. O. and László, A. The Uniform-Section Disk Spring. Trans. ASME 1936: **58**, 305-314.

Garzon, Reuben D. High Voltage Circuit Breakers, Design and Applications. Marcel Dekker, Inc., New York, 1997.

Kussey, Frank W.and Jack L. Warren. Design Fundamentals for Low-Voltage Distribution and Control. Marcel Dekker, Inc., New York, 1987.