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TECHNICAL NEWS

INDUSTRIAL SWITCHGEAR & AUTOMATION SPECIALISTS

THERMAL SIMULATION OF SWITCHGEAR

Introduction:

Low voltage switchgear is becoming increasingly miniaturised and the performance requirements of modern devices is increasing due to customer demands. This can produce a dramatic increase in operating temperatures both within the device and the surrounding areas, including at the wiring terminals. The correct thermal design of switchgear therefore becomes more important to provide safe and reliable operation.

Due to the complexities of heat generation and loss processes, along with the difficulties experienced when trying to measure these variables in a test situation, it is becoming increasingly attractive to turn to computer thermal simulations to model the ways in which low voltage switchgear creates and dissipates thermal energy.

By embracing new technologies and utilising advancements in computer simulation technology, it is possible to develop new products whilst monitoring the expected temperature heat rise within the device. The accurate analysis of internal temperature rise and thermal conduction/convection within a simulated design subsequently leads to:

- Switchgear products being developed which are thermally stable,
- Have an overall smaller size and
- Provide many safe and reliable switching operations

NHP's range of Sprecher + Schuh contactors and circuit breakers (figure 1), have for some time now been designed and simulated for thermal heating effects using a basic computer simulation model. This thermal simulation model has only concentrated on a single entity – i.e. the contactor or the circuit breaker. The next generation '3D' thermal simulation models utilised by Sprecher + Schuh are aiming to explore the thermal effects of combined contactor/circuit breakers and motor starters.

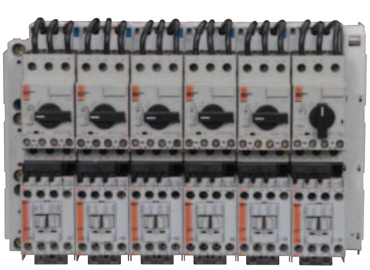

Figure 1 - Sprecher + Schuh ACS system

The use of computer simulations supersedes tedious and time consuming developments by 'trial and error', required to achieve temperature coordinated motor starter combinations.

FEATURES:

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Thermal Simulation Design & Required Inputs:

This revolutionary 3D thermal simulation can be achieved by combining well known contact physics and mechanical engineering fundamentals of the contactor, circuit breaker and the thermal overload. The contactor is the primary focus of the model and taking into account numerous design aspects of the switchgear helps to develop an extremely accurate thermal model of the motor starter system.

These aspects include (but not limited to):

- The contact specifications
- Modelling the switching arc's heat transfer during high load operations
- The applied tightening torque of the wiring terminals, and
- Considering the heat flux effects through the housing of the device.

The contacts of the device are modelled as a resistance located between the contact points. Due to the arc occurring at the instance of switching, this dramatically increases the temperature within the contact area and therefore the higher temperatures dramatically change the resistance of the contacts. The resistance of the contacts at high currents and high temperatures is given as:

$$Rk_{contact} = C_1 \cdot \frac{\overline{H_k}}{F_k}(1 + C_2 \ T), \quad (1)$$

F_k	contact force;	T	temperature of difference;
H_k	contact hardness;	$C_{1,2}$	constants

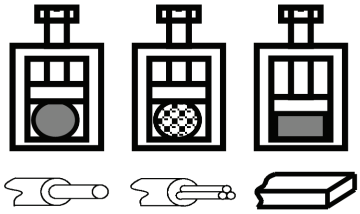
From the equation above, it can be seen that the contact resistance is primarily influenced by the contact force F_k and the contact hardness H_k of the contacts.

Table 5 of AS/NZS 60947.4.1-2004 (Low Voltage Switchgear and Controlgear – Contactors and motor starters, Electromechnical contactors and motor-starters) specifies the maximum temperature heat rise at the terminals during type testing of a contactor. The maximum temperature heat rise at the terminals of the contactor is affected by the clamping joint which in practice are contacts held together by means of a screw and washer system. The torque applied to the screw at the terminal changes the terminal resistance (in addition to the contact resistance explained above), and can greatly affect the temperature rise at the contactors terminals.

The terminal resistance ($Rk_{terminal}$) is given by:

$$Rk_{terminal} = \frac{constant}{F_k^m}, \quad (3)$$

F_k contact force;
m geometrical coefficient



a) b) c)

Figure 2 - Typical wiring geometrics within wiring terminal.

The geometrical coefficient (m) varies from 0.5 for cylindrical conductors being pressed against a flat surface up to 1 for a rectangular conductor being pressed against a flat surface (figure 2).

The contact force F_k required for equation (3), can be deducted for a given screw size from the expression below relating tightening torque M_t and contact force F_k.

$$F_k = constant \bullet M_t \{[2d_s+(d_w+D_H)]+\tan\varphi\}^{-1} \quad (4)$$

M_t	tightening torque on screw;	d_s	screw pitch diameter;
d_w	washer face diameter;	D_H	clearance hole diameter;
$\tan\varphi$	pitch angle screw		

Substituting this value of Fk into equation (3), it is found that typical values for the terminal resistance ($Rk_{terminal}$) of a cylindrical copper wire to a copper terminal at room temperature (25 °C), with a terminal tightening torque of 3Nm is approximately 25$\mu\Omega$.

The switching arc of the contactors can be modelled by its voltage V_{arc}, the current i and the duration t_{arc}. Each of these values is generally theoretically defined during the prototype stage or from actual switching tests. The heating of the contacts results from the switching of the contactor. For currents ≥ 200 A and with contact gaps of approximately 6 mm, about 40-60 % of the arc energy will be transferred directly into the contact terminals. The switching arc is well known to differ between the initiation and completion of the arc which means that the thermal simulations would only take a median value for these heat transfer figures – i.e. roughly 50 %.

Convection Issues:

It is interesting to note that it is not only the internal parts of the contactor which entirely dictate the quality of the device – the outer plastic components which generally support internal components can also play an important part in the overall integrity of the contactor under high load and high temperature conditions. Even the volume of air contained within the contactor can determine whether it will be successful in the field. This is due to the convection occurring when the motor starters are installed in typical installations and therefore restricting the flow of air inside and around the devices.

Generally, motor starter circuits are installed side by side in a control cabinet. For the purpose of the thermal simulation model, the main parts of the contactor are modelled using their actual volumetric shape however the many smaller pieces making up the mechanism of the device can be simplified into a single volume in order to keep modelling as simple as possible. This is completed to ensure the heat conduction through the internal parts of the contactors is taken into account. As mentioned above, from the way the motor starter circuits are installed within the control cabinets (figure 1), it can be interpreted as convection occurring around a long bar (figure 3). The coefficient of convection (α- a function of both the surface temperature and the environment temperature) can be expressed in terms of the simulated 'long bar' dimensions and the fluid parameters of air.

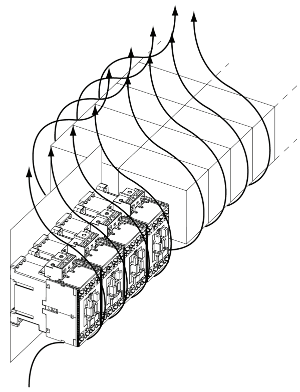


Figure 3 - Convection along a row of devices can be interpreted as convection across a long horizontal bar.

Thermal Simulation Results:

Simulated inputs of the coil of the magnetic trip unit and thermal overload are required in conjunction with the simulation inputs discussed above to make up the motor starter combination. Both parts, especially the bimetal heater, are considerable heating sources and greatly affect the overall outcome of the thermal simulation.

From initial tests comparing the simulation results to test results, the accuracy can be seen to approach 90 %. Two explanations can be given for this deviation: the influence of tolerances of dimensions and material properties as well as between measurements and the fact that the simulation model does not take into account the ferromagnetic material parameters of the device – i.e. eddy currents. Model simplifications may also cause the simulation results to differ slightly from measurements.

Figure 4 shows the functional groups responsible for the overall heating effects within the motor starter as calculated from the simulation. It can be seen that over 40 % of the heating which effects a circuit breaker, occurs from the contacts sub-groups:

- Terminal contact resistance,
- Main contact resistance, and
- Contact bridge.

It is these areas of contactor design which influence the overall success of the contactor and therefore the overall success of the motor starter.

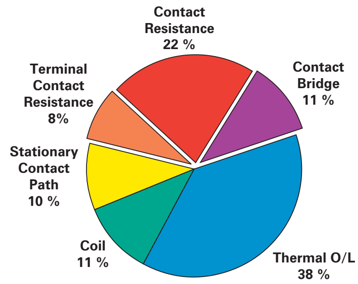


Figure 4 - % Power loss within motor starter circuit.

Conclusion:

This revolutionary 3D thermal simulation technology designed and tested by Sprecher+Schuh, will in the near future be the standard - not the exception - for the design and testing of temperature rise within contactors and circuit breakers. Simulation technology within the switchgear industry will only further improve producing products which are smaller, have a higher number of switching operations and are more stable to changes in internal temperature conditions. This thermal simulation technology allows you, our customers, to profit from the fact that our range of Sprecher + Schuh contactors and circuit breakers are optimised for common model cases. It is hoped that in the future this technology will one day be available for analysing individual customer requirements.

NHP is proud to be a part of Sprecher + Schuh's commitment to this new and exciting technology and are excited that we can provide this level of technology to our customers. NHP look forward to helping you with all aspects of your motor starting needs and as detailed above, the technical support and confidence in our motor starter combinations will be even further enhanced.

References:

(1) J. Paulke, P. Steinhaeuser and H. Weichert, 'Thermal Simulation of Switchgear', in Proceedings of the 47th Holm Conference, Montreal, 2001, pp. 6-11.

(2) Peter U. Frei and Hans O. Weichert, 'Advanced Thermal Simulation of a Circuit Breaker', Joint 22nd International Conference on Electrical Contacts and 50th IEEE Holm Conference on Electrical Contacts, Seattle, 2004.

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