

Simulating with SPICE - an electromechanical example.

In this study we look at how SPICE can be used to model a relay in some detail. The schematic shows the full model which is split into the following parts :

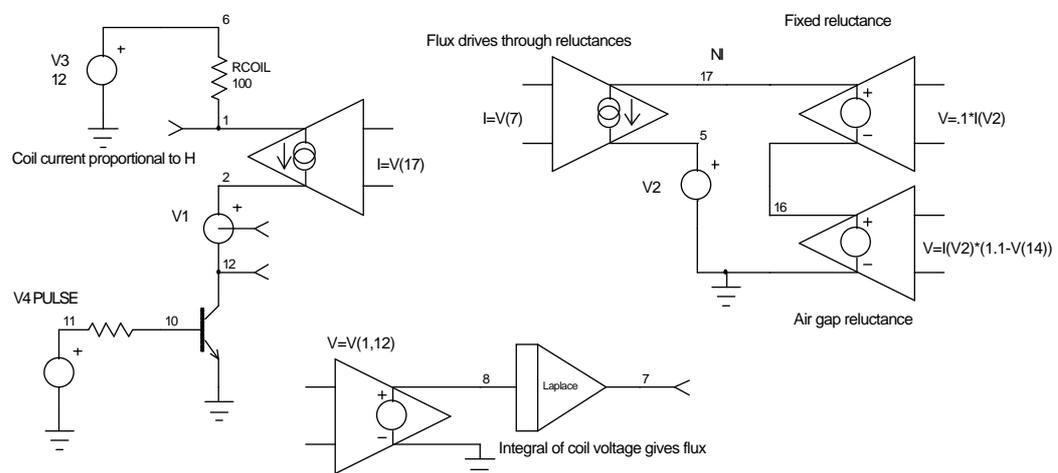
The coil and drive.

The transistor drives the coil which is represented by the components between the collector and supply, V3. We might usually think in terms of using a voltage source in the coil circuit to develop the back emf but this implies differentiating the flux in the magnetic circuit. In this example we integrate the voltage across the coil (less the resistive drop) to obtain the flux, node 7. Integration is always preferable to differentiation plus the LAPLACE function requires the denominator order to be greater than the numerator.

The magnetic circuit.

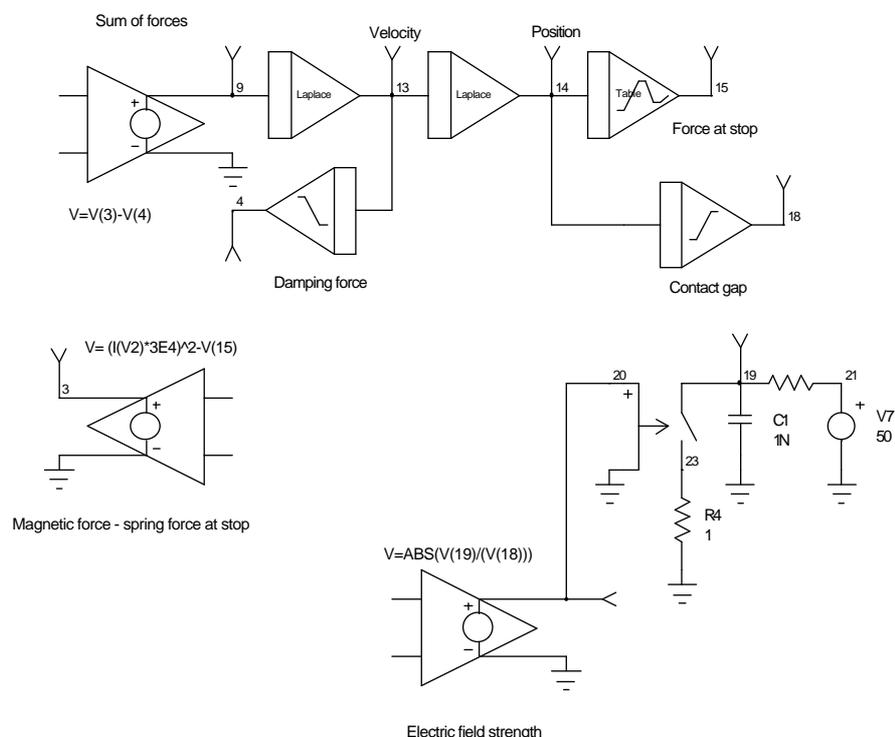
The reluctance of the magnetic circuit has two series components, that of the fixed iron and air path and the changing solenoid air gap. For simplicity we assume no fringing and a linear relation between gap and reluctance.

Flux flows through the series combination of the reluctances to give a "potential" which is the ampere-turns. From the ampere-turns we have the current flow in the coil.



The magnetic force.

The magnetic force on a body is the integral of the square of the normal component of B over the surface. For a simple solenoid plunger with little fringing we can assume B squared times plunger face area. This in turn is the square of the flux divided by area.



The moving air gap.

The plunger acceleration is the result of the sum of the forces acting on it.

The acceleration can be double integrated to obtain position with time.

The other forces acting on the plunger are friction and that from the hard stop.

Friction is calculated from velocity by using a high gain limiter, this gives a constant force the sign of which is dependent on the direction of movement, i.e. static friction.

The characteristic of the stop is obtained from a table model which gives a high spring rate for negative gap.

The gap is fed back into the magnetic circuit to control the reluctance.

Arcing.

The solenoid plunger is connected to the relay contacts. The contact gap closes before the plunger hits the end stop. A limiter function is used to generate the contact gap from plunger position. Arcing will occur when the electric field strength across the gap exceeds a certain value. By calculating the field strength and applying it to a switch we can short out the relay contacts to simulate arcing.

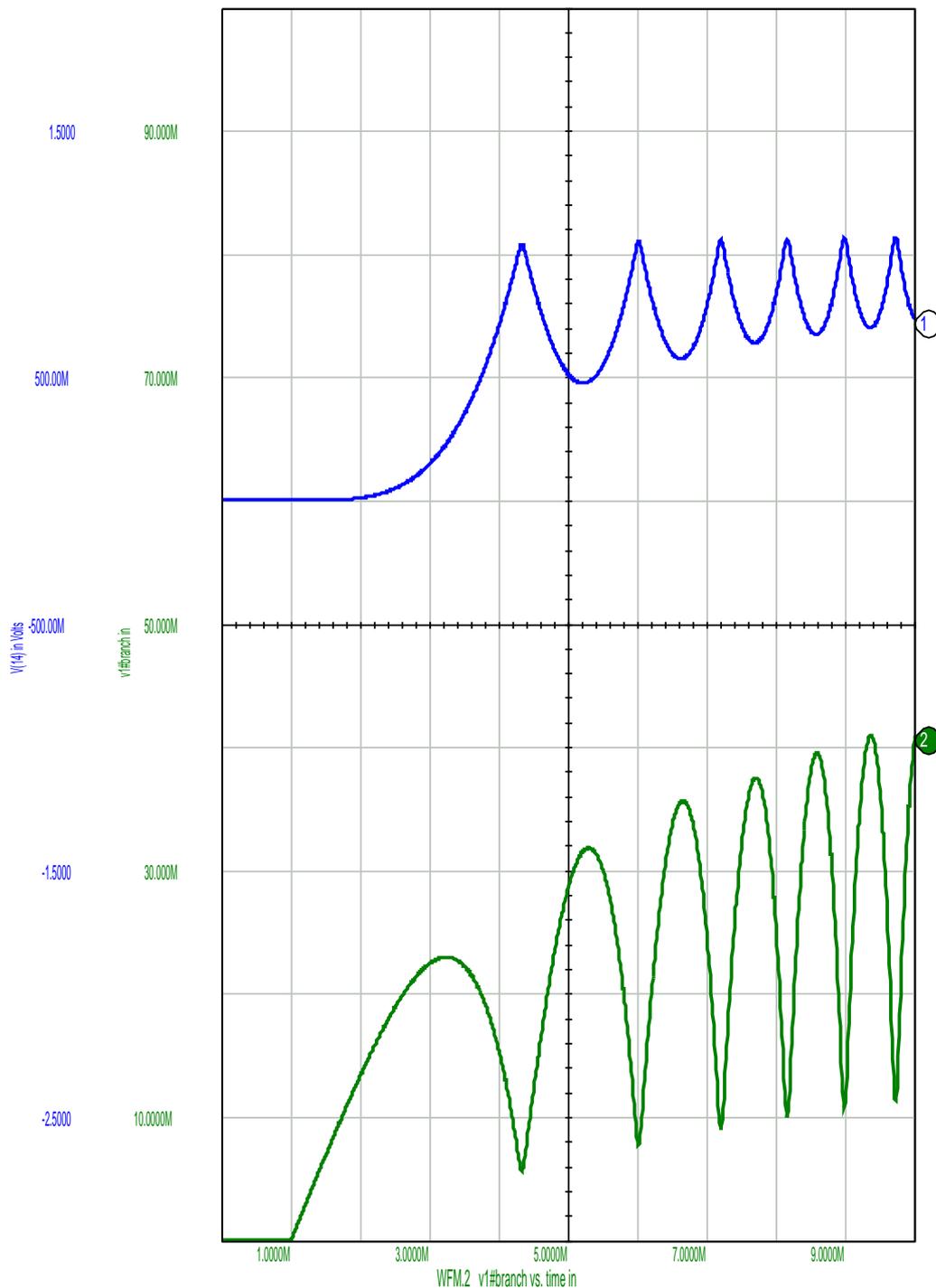


Figure 1

Results.

The plot of figure 1 shows the plunger bouncing off the end stop following coil energisation and the rise of current in the coil. Figure 2 shows some detail of arcing at the contacts, node 19, and the contact gap, node 18.

Comments

The constants chosen in this example are purely arbitrary and do not purport to represent any real device. When modelling a real device it would be relatively easy to introduce some second order effects such as non linear reluctance change with air gap by using either the equation facilities in the B source or using the table model to introduce data obtained from a field modelling package.

As the air gap widens fringing increases and the effective magnetic path length becomes longer than the gap. This can be introduced as a second order term in the B source e. g..

$$B4 \ 16 \ 0 \ V=I(V2)*((1.1-V(14))+(1.1-V(14))^2)$$

For version 7.6 users the B source can be replaced by a resistance expression :

$$Rgap \ 16 \ 0 \ R=(1.1-V(14))+(1.1-V(14))^2$$

As presented the stop is perfectly elastic, energy loss in the stop can be added by subtracting another force computed from the stop force times plunger velocity. Try changing B10 to read :

$$V=V(3)-V(4)-V(13)*V(15)*.0001$$

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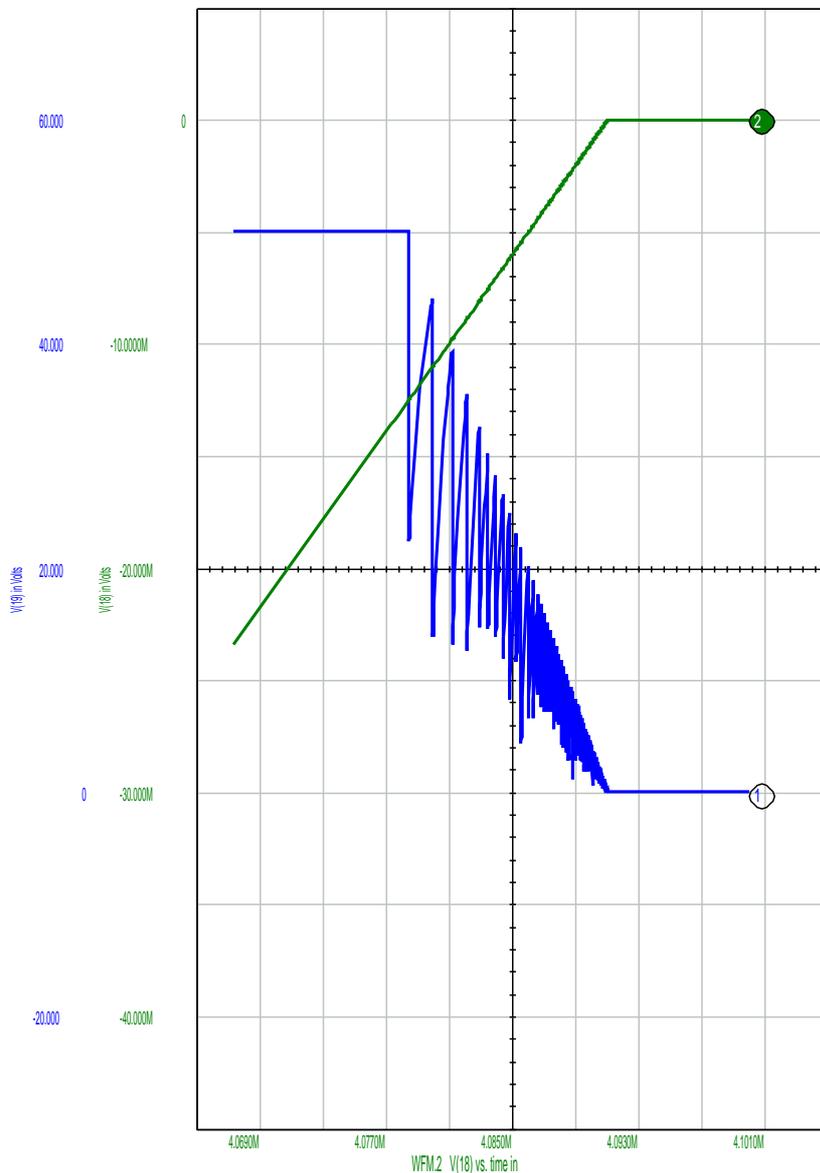


Figure 2