High-dynamic Proportional Solenoid on basis of Established Production Technologies

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Proportional solenoids generate a proportional force effect from an electrical input signal. The force is created between the movable armature and the magnetizable counter-piece. Due to this known physical effect and inherent to the functional principle, the magnetic force can actuate in one direction only. The return movement is made by a spring. Based on this principle the realization of well controllable hydraulic and pneumatic valves is possible. The novel solenoid design developed at MSM enables a bi-directional force effect. For this, particularly the armature is considerably modified and fitted with permanent magnets. In addition to the influence of the force direction, the pre-magnetisation of materials causes a considerable improvement of dynamics.

Keywords: solenoid, high dynamic, proportional valve, hydraulic
Target audience: Actuators and Sensors

1 Introduction

It is known that proportional solenoids serve to transform an electrical control signal into a proportional force effect. The high-pressure resistant tube is an important element of the constructive design for hydraulic valve applications. In turn, this tube is enclosed by a coil and the appropriate iron parts so that a suitable iron circuit is created. By energizing the coil a magnetic flow is generated in the iron part now. The tube is equipped with a non-magnetic separation in order to have a suitable effect on this flow. Thus, the magnetic field lines are conducted into the armature. They act via the head surface of the armature and the surrounding geometry in such a way that a proportional force effect is generated.

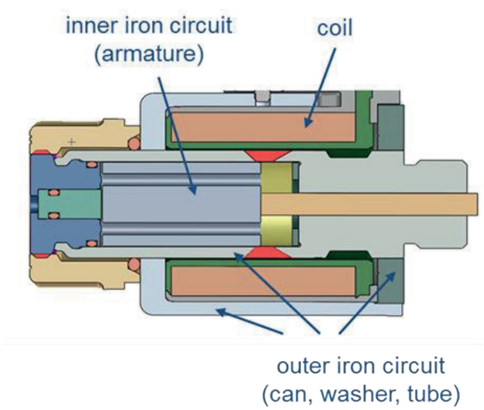

Fig. 1: Constructional design of a conventional proportional solenoid

In order to achieve a bi-directional force effect, the armature of the proportional solenoid is conside modified. It consists of permanent solenoids as well as discs made of conventional ferromagnetic material also modified pole tube has been only slightly adapted in the area of the magnetic separation. The armature with permanent solenoids is arranged at a suitable position in the slightly modified pole tube. Due t symmetric arrangement the permanent magnetic forces neutralise each other in neutral position. A standar is used for the generation of the magnetic flow. During the energization of this coil, a nearly proportio acting bi-directional magnetic force is created.

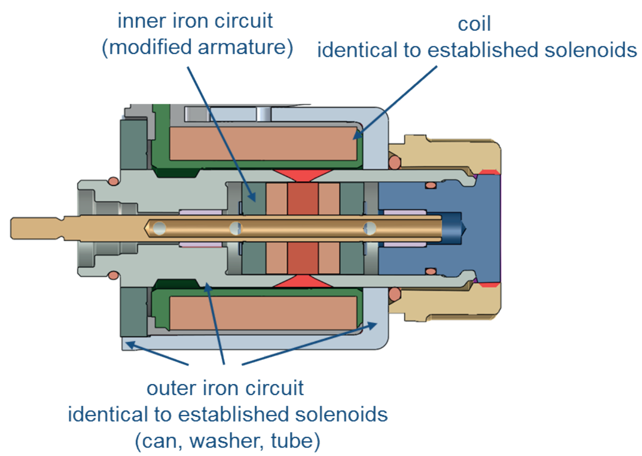

Fig. 2: Constructive design of the bi-directional proportional solenoid

In the presented iron circuit a magnetic flow is generated by the electric coil in combination with the perma magnet. By energization of the coil in two directions the corresponding magnetic flow changes direction. S overlap generates a bi-directional force. The following figure shows the overlap of the magnetic field line simplified way.

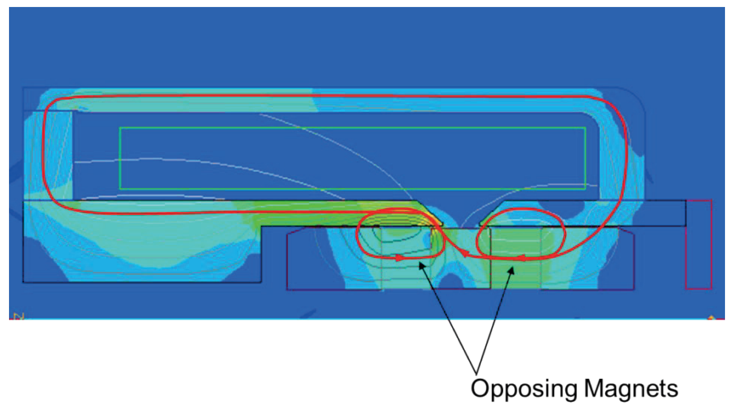

Fig. 3: Bi-directional force effect (FEM), both directions

The generated force is shown in figure 4. For clarification of the applicability in hydraulic valves the wo areas are highlighted in colour, the bi-directional effective direction of the forces can be identified b positive and negative scaling.

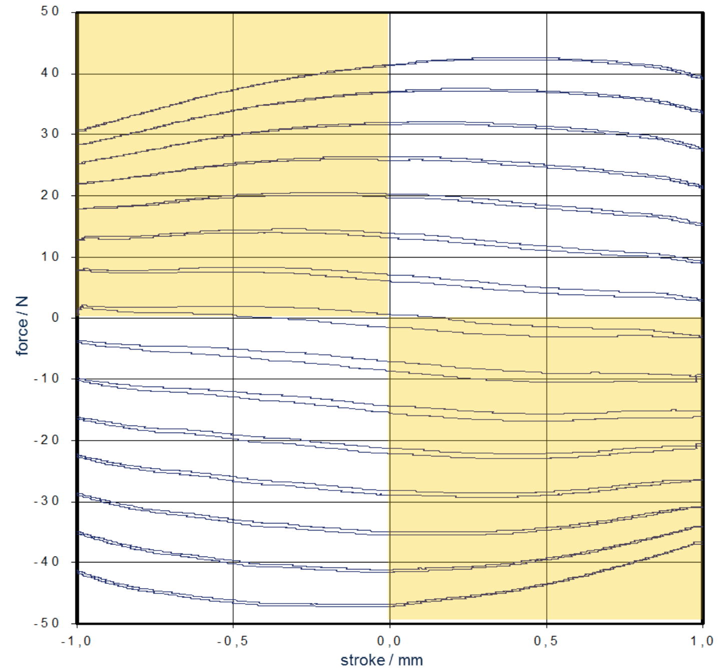

Fig. 4: Force vs. stroke characteristic diagram

The armature design as combination of permanentmagnetic and ferromagnetic sections is responsible for the fundamental bi-directional effect. Additionally the geometric design of the so-called cone geometry is a further possibility to influence the force characteristic diagram. Similar to conventional proportional solenoids, the working stroke and the increase of the characteristic curve is adjusted to the application. In figure 5 two characteristic diagrams are exemplarily overlapped as an example with considerably different characteristic so that the variation possibilities are clearly visible.

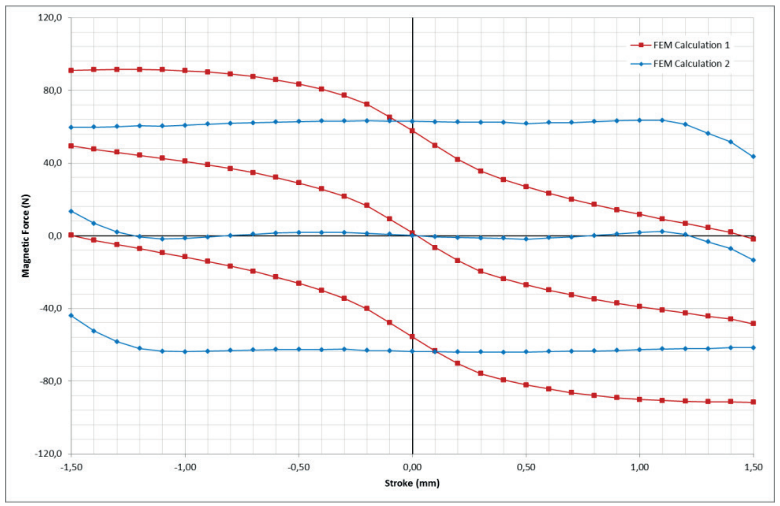

Fig. 5: Comparison of different characteristic diagrams

The here presented solenoid drive is perfectly suitable for appropriately adapted control valves. Such control valves can use the advantage of the bi-directional force effect because they can be well designed with the considerably reduced construction space and the assembly on only one side of the valve block. The next figure no. 6 optically illustrates the advantages of the construction space.

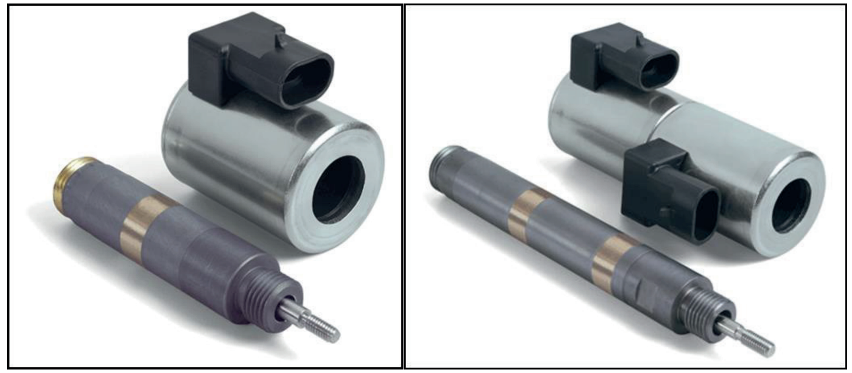

Fig. 6: Comparison of the construction space: conventional / bi-directional solenoid

In order to be able to use the advantages of the reduced construction space, constructive adaption works are necessary. The stroke movement must be transferred bi-directionally to the valve slide. Whereas the force transfer in push direction is uncomplicated, a positive connection must be provided for the opposite direction (e.g. via thread). In addition, the performance of the bi-directional solenoid must be compared to the conventional variant. In figure 7, the characteristic curves of the new solenoid have been compared to the force vs. stroke characteristic field of a conventional solenoid under the same current feed. The bi-directional solenoid shows a similar force behaviour as a conventional solenoid. This comparison also shows that in the direct comparison with a double actuated valve, adaption works at the valve will be necessary regarding the spring force and the hydraulic design.

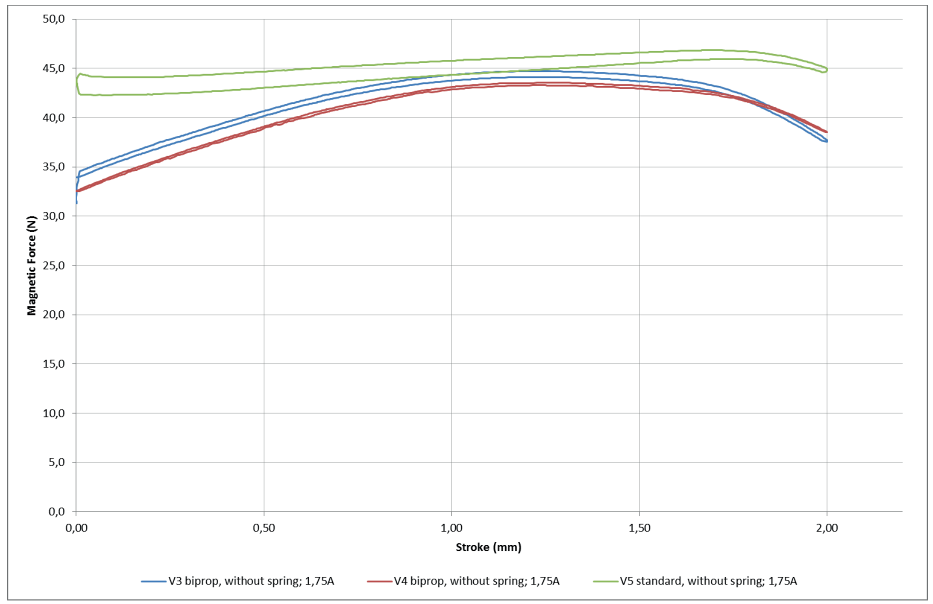

Fig. 7: Force comparison: conventional / bi-directional solenoid

The replacement of 2 conventional solenoids by a novel bi-directional solenoid is a challenging task requiring constructive adaption works. For new developments, the constructive boundary conditions can be well adapted to the solenoid properties. A common requirement for the solenoid size 35 mm is a force of around 20 N with a stroke of +/- 0,75 mm. Against this background, the maximum achievable force can be positively assessed also in direct comparison to conventional solenoids.

Besides the static forces, the dynamic features are important for the use in control valves. With conventional proportional solenoids, the iron material is more and more magnetized for force generation on the basis of the non-magnetised condition by the coil energization so that the actuation force is generated depending on the magnetisation properties of the materials. For dynamic applications, this correlation has the property that the non-linear effect of the complete magnetisation of the materials must be processed (see figure 8). This causes a fundamental dynamic disadvantage in build-up of force and finally a limited valve dynamics. This dynamics is sufficient for a huge part of hydraulic valves.

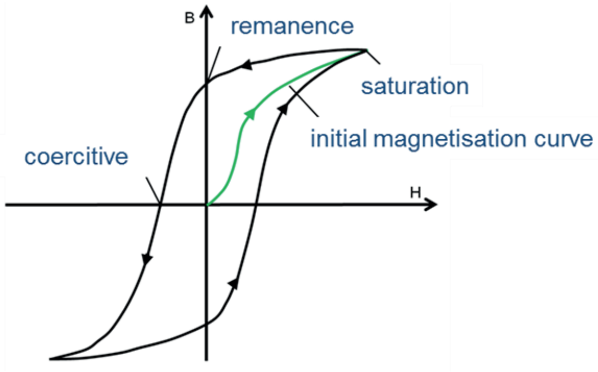

Fig. 8: Typical magnetisation characteristic curve (B-H-characteristic)

A considerable increase of dynamics can be principally effected by a pre-magnetisation of the material. It can be effected e.g. with a basic energisaton or the installation of permanent solenoids. This is, however, not useful in a conventionally designed solenoid system because an unwanted force effect is directly generated.

The new design of a proportional solenoid developed at MSM avoids this negative effect and generates a high dynamics with sufficient force density at the same time. As already described, the armature of the proportional solenoid is considerably modified for this purpose and fitted with permanent magnets as well as discs of conventional material. Due to the symmetrical arrangement, the permanent-magnetically generated forces neutralise each other. So, there is no unwanted force effect but the materials take a considerable pre-magnetisation.

The considerably higher dynamics compared to the conventional proportional solenoids could be proved by measurings (see figure 9). The time constant of the new solenoids is lower by the factor 2 to 3. Another advantage is that the considerably lower inductance is nearly independent of the armature postion.

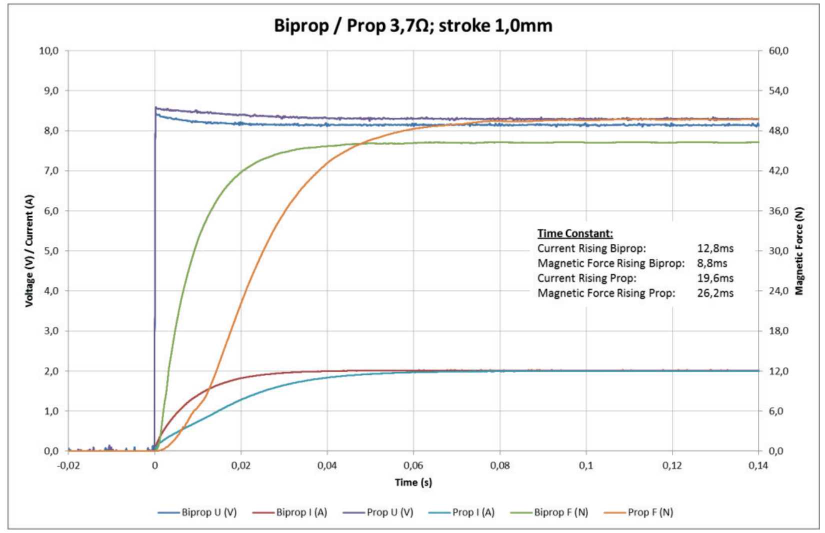

Fig. 9: Step response behaviour

Another effect of pre-magnetisation concerns the force vs. current characteristic curve. Due to the positive effect of pre-magnetisation, a characteristic curve is generated which shows a directly increasing force effect in the lower current range (see figure 10).

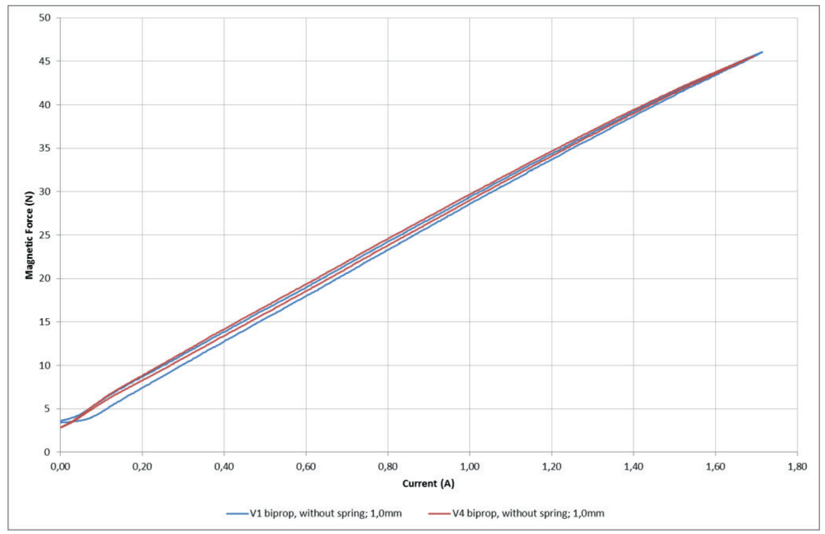

Fig. 10: Force vs. current characteristic curve

The shown measurement data and presented notes on the function illustrate the good applicability of such solenoids in hydraulic valves. The bi-directional solenoid has further advantages in the application. It can be designed with only slightly modified pole tubes and the appropriate standard coils. So the user has the possibility to design a highly dynamic valve function by the change of the proportional solenoid without modification of the geometric and electrical interfaces. A system change of the actuator function is not necessary. Only the current control must be modified. Figure 11 illustrates in a simplified way the constructive design of a conventional pole tube and of the armature.

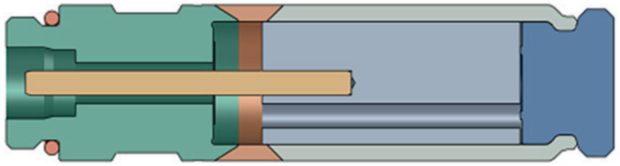

Fig. 11: Constructive design of conventional pole tubes and armatures

For the sector of the high-pressure resistant proportional solenoids, Magnet-Schultz has developed a structured modular system. Within this system, a large variety of functions can be illustrated with production processes for large series by the use of similar components. At the same time, individual customer requirements can be realised. Within this modular system, also ON/OFF solenoids with reduced functional quality can be produced besides challenging proportional solenoids. A survey of this modular system is shown in figure 12.

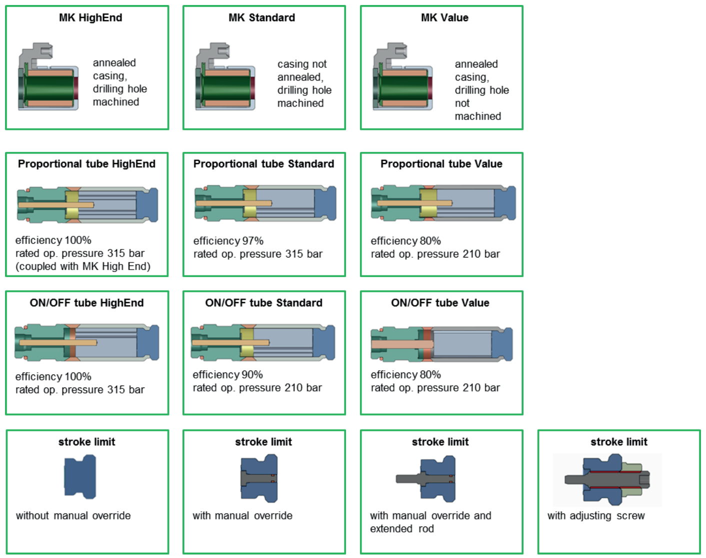

Fig. 12: Modular system for hydraulic solenoids

Due to the constructive design of the here presented high-dynamic proportional solenoid, the manufacturing advantages of the modular system can be used. The production technology for the pole tube and the solenoid coil correspond completely to the currently used principles. The single parts of the armature are also conventionally producible. Only the assembly poses higher demands due to the permanent magnets

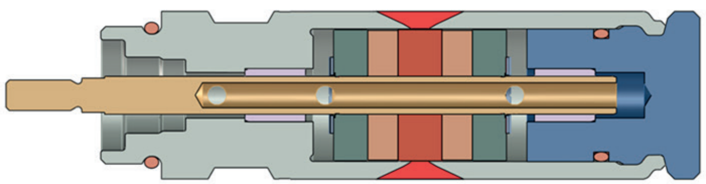

Fig. 13: Constructive design of pole tube and armature at the bi-directional solenoid

In this contribution, a high-dynamic and bi-directionally effecting solenoid has been presented. The illustration of functioning and the constructive design explain the advantages of the solenoid for the realisation of a high-dynamic valve function. At the same time, the used construction principles and the appropriate production procedures are established in large series. So, this is a combination of technical advantages while using conventional production procedures. Under these conditions, a successful use can be also expected in small series with comparably moderate development effort.

References

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