Innovation Services

High-precision equipment

Comparative Evaluation of Lorentz and reluctance actuators

High-precision engineering example

Historically, Lorentz actuators (based on current carrying windings situated within a magnetic field) are widely used to achieve the highest level of force predictability. However, their limited force density result in significant heating of the coils and in local hot spots.

A significantly higher force density and steepness can be achieved by reluctance actuators, which are based on attraction force exerted on a ferromagnetic mover by a ferromagnetic armature magnetized by a coil. However, these latter actuators suffer from larger parasitic effects, impacting their force predictability. Recent developments at Philips Innovation Services help overcome these shortcomings historically associated with reluctance actuators.

Current status Lorentz and Reluctance actuators

The ideal electromagnetic actuation principle highly desirable from the high-precision perspective is an actuator with a linear relation between force and current, meaning the motor constant should be independent of position, current level, speed, temperature, tolerances and environment.

The Lorentz type actuator is close to the ideal actuator, with only small adverse effects. These, however, become important when accuracy requirements increase. Besides this, the relatively low force density and steepness which results in high power dissipation, have become an important disadvantage. One typical example of a Lorentz actuator is shown in Figure 1.

The reluctance actuator, schematically depicted in Figure 3, shows a nonlinear dependence of the force on the actuator current (≈quadratic, see Figure 5) and a strong dependence of the force on the gap (≈ hyperbolic). These non-linear force-current and force-gap relations and the high force variation are the major reasons why the reluctance type of actuators has not been implemented in the past in high-precision systems.

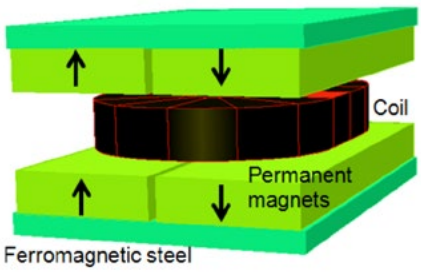

Figure 1: Lorentz type of actuator

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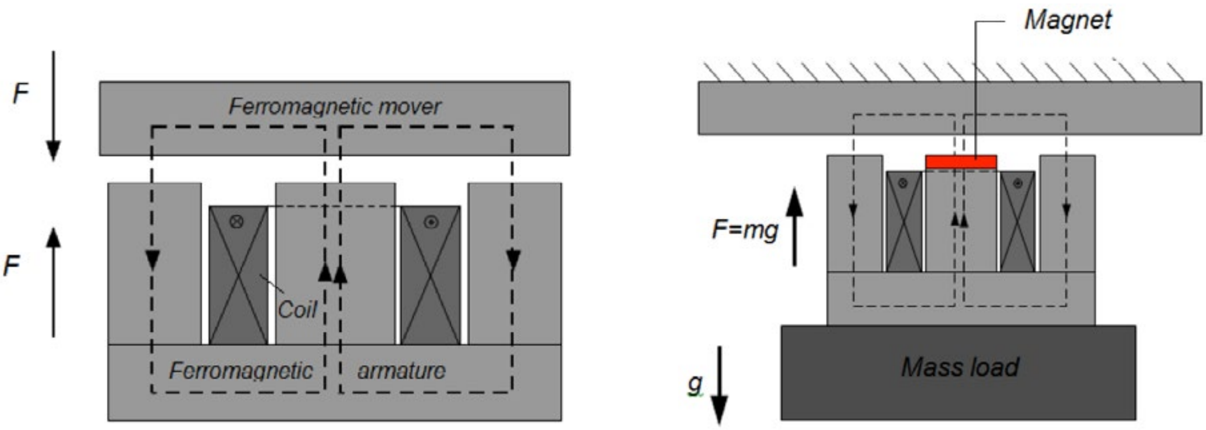


A B

Figure 3: Reluctance type of actuator (A) Bidirectional reluctance type of actuator combined with gravity compensation (B)

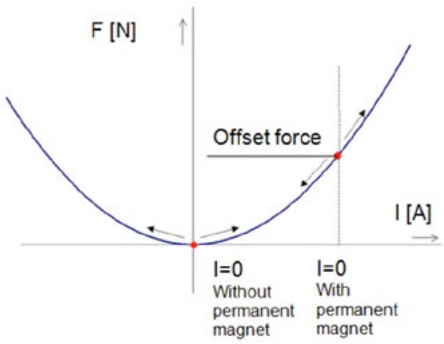


Figure 5: Bidirectional actuation enabled by permanent magnet gravity compensation within a reluctance actuator

Recent developments

During the last decade, significant improvements have been achieved in the field of increasing the force density. One industrially successful example, based on internal developments within Philips Innovation Services, is the implementation of foil coils (either copper or aluminum) instead of the classical copper wires (see Figure 9). The thermal uniformity of the heated coil will improve significantly (see Table 2) and consequently will reduce the undesired hot spots.

A B

Figure 9: Copper (A) and aluminum (B) foil coils

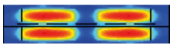
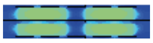
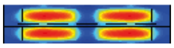
Tmax [°C]	Copper-wire-winded coils	Aluminum-foil-winded coils
Same heat load	 112	 67
Same force (current density)	 112	 92

Table 2: Thermal uniformity of aluminum foil coils vs. copper wires

Also in the field of reducing parasitic effects some major advancements have been made. Traditionally there are two methods of controlling the reluctance actuator. One option is to use flux control (see Figure 10-left) which makes the force gap independent. This method is simple and requires little software compensation effort but the final negative stiffness reduction is only 80%.

A second more effective option is to use current control (see Figure 10-right) which makes the force strong gap dependent. This can be compensated by using a sensor to measure the airgap. This method reduces the negative stiffness significantly (by 99%), at the cost of more complicated software compensation effort.

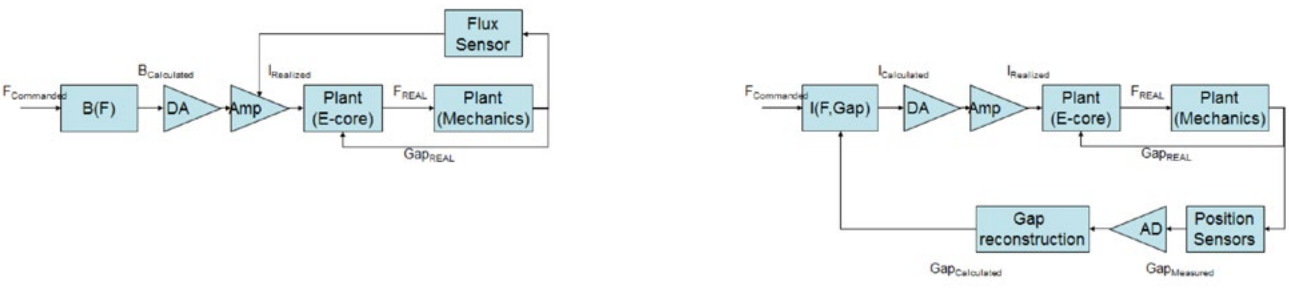


Figure 10: Flux control (left) and current control (right) diagram of a reluctance actuator

Recently, the reluctance type of actuators have successfully been used at Philips Innovation Services within a specific industrial application: using current control of a reluctance type actuator, standstill performance was demonstrated of a dozen picometers (3σ, ~10 kg moving mass on vibration isolation table).

Towards future requirements

To meet future requirements Lorentz actuators developments should address thermal management improvements by e.g. applying different coil topologies, novel forcer built-up and innovative cooling strategies. On the other hand, reluctance actuators should build upon further developments in advanced control strategies (profiting from developments in computing power and software flexibility), accurate sensing systems and new armature designs.

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