Chapter 1
Introduction

S. Büttgenbach[1], A. Burisch[2]

[1] *Institute for Microtechnology*
Technische Universität Braunschweig
s.buettgenbach@tu-braunschweig.de

[2] *Institute of Machine Tools and Production Technology*
Technische Universität Braunschweig
a.burisch@tu-braunschweig.de

1.1 Initial Situation

Microsystem technology has progressed rapidly over the past few decades and plays an ever-growing role in the development of innovative technical products. In microsystems, sensors and actuators are integrated with information processing components resulting in compact and lightweight devices which offer further benefits, such as low energy consumption, high reliability, adaptivity and improvement of the cost-benefit ratio. Microsystems cover a broad range of application areas such as car manufacturing, biomedical engineering, communications technology and environmental protection. A major factor here is the fact that microsystems are used to add value much higher than the value of the microsystems themselves.

Whereas the field of microsensors is already highly advanced, microactuators are still in a more basic development phase, although microactuation opens up a multitude of important new opportunities to microsystems. Initially favored microactuation principles were electrostatic and thermal actuation because all processes for the fabrication of these microactuators were available from currently existing microelectronics technology. Principles technologically more difficult to realize have developed more slowly, for example piezoelectricity, shape memory alloys, pneumatics and hydraulics.

Magnetic microactuators exhibit considerable advantages such as high forces, large deflections, low input impedances and thus, the involvement of only low voltages. However, the basic structure of magnetic microactuators has imposed limitations for their broad adaptation. Key elements include three-dimensional microcoils and complex hard and soft magnetic microstructures, which correspond to wound coils and magnets in bulk actuators, respectively. In addition, in order to achieve high forces, both the electric conductors of the microcoils and the flux guiding structures of the magnetic circuits have to be fabricated in such a way that they allow for sufficiently high current and magnetic flux, respectively. These constraints require tech-

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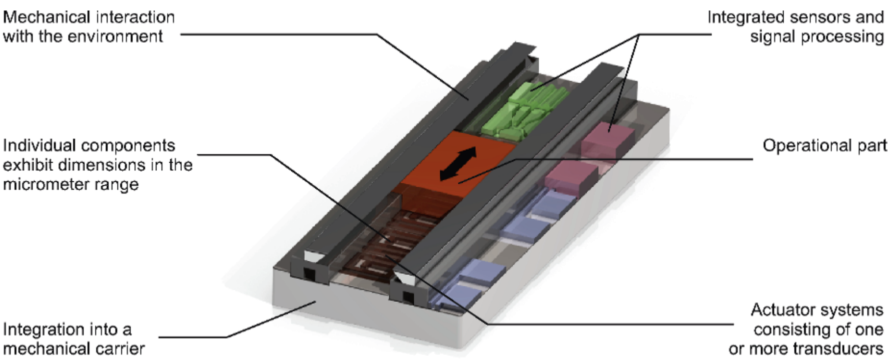

Fig. 1.1 Schematic of an active microsystem as defined in the context of the Collaborative Research Center

nologies to facilitate the fabrication of hybrid microsystems made of complex three-dimensional microstructures with high aspect ratios.

In particular, microactuators are an essential component of active microsystems, which can be characterized by the following features (see Fig. 1.1): sensors, signal processing functions and actuator systems consisting of one or more transducers are integrated into a mechanical carrier. The total construction size of the system is typically in the range of several centimeters whereas essential structures are in the micrometer range. Such a typical hybrid microsystem is made of several different components and types of materials (see Fig. 1.2). For the successful development of systems based on magnetic actuators, further technologies and processes are required for the fabrication of microcoils and magnetic microdevices. These include handling and bon-

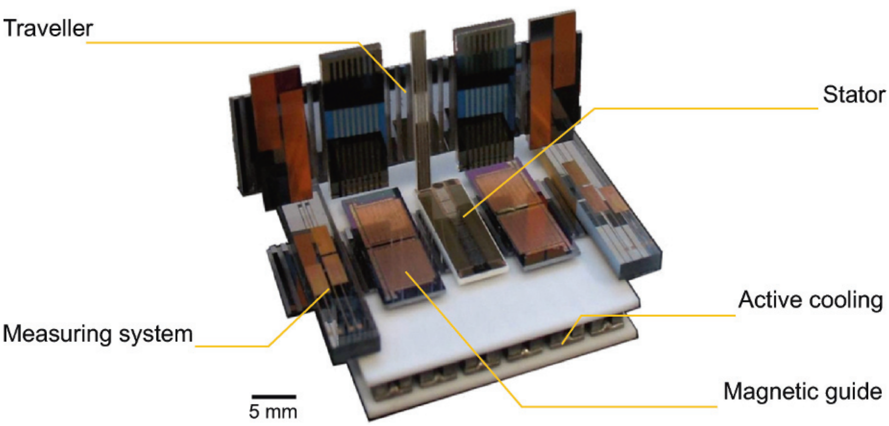

Fig. 1.2 Test setup with components of a linear microhybrid stepper motor

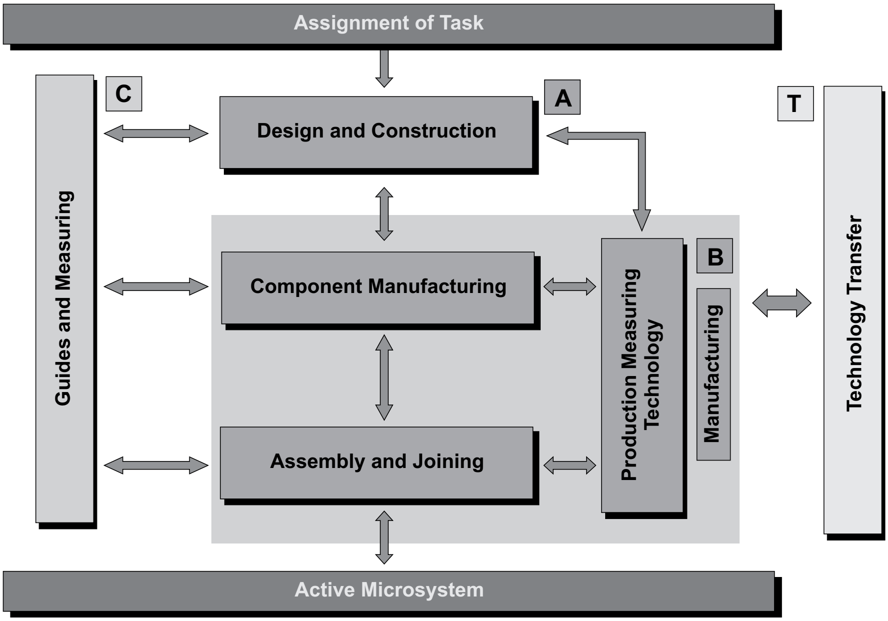

Fig. 1.3 Structure of the Collaborative Research Center

ding techniques, production measurement technology, guides and measuring techniques, and design engineering methods.

In order to tackle these challenges and to stimulate the development of magnetic active microsystems for a variety of applications, the Collaborative Research Center "Design and Manufacturing of Active Micro Systems" (Sonderforschungsbereich SFB 516) has been established at the Technische Universität Braunschweig. Five institutes belonging to the Department of Mechanical Engineering of the Technische Universität Braunschweig as well as institutes of the Leibniz Universität Hannover and laboratories of the Fraunhofer-Institut für Schicht- und Oberflächentechnik, the Physikalisch-Technische Bundesanstalt, and the Laserzentrum Hannover are involved in the Callaborative Research Center. It consists of 17 subprojects and is subdivided into four main project groups (see Fig. 1.3). Project group A deals with design engineering methods, project group B centers on microproduction technologies and project group C is dedicated to guides and measuring techniques. Project group T was established during the last phase of the research center and focuses on the transfer of selected technologies into industrial applications.

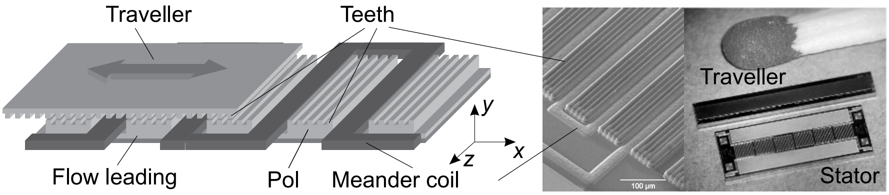

Fig. 1.4 Concept of a linear variable reluctance micromotor

1.2 Prototype Concepts for Active Microsystems

In order to evaluate the performance of the various technologies developed, several miniaturized stepper motors with a travel in the order of several millimeters were designed, fabricated, assembled and characterized. Figure 1.4 presents the principle of the initial prototype, a variable reluctance linear microactuator, in which the magnetic flux crosses the air gap perpendicular to the wafer plane. In the course of the research activities this concept has been expanded in many respects.

In order to compensate for the Maxwell normal forces between stator and traveler, which are common to any electromagnetic motor which uses soft magnetic material, the so-called "horizontal reluctance stepping motor concept" (Fig. 1.5.b) was developed. In this design, the horizontal magnetic flux generated by 3D meander coils (see Fig. 1.5.a) attracts the traveler poles from both sides, compensating for the normal forces. This results in very low friction forces, allowing for the implementation of a purely tribological or a

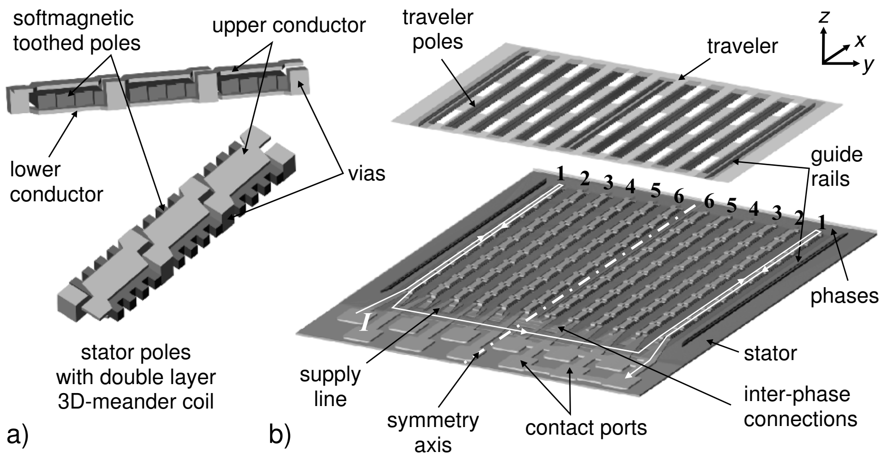

Fig. 1.5 Concept of a linear variable reluctance micromotor with horizontal flux guidance: (**a**) Meander coils; (**b**) Complete system design

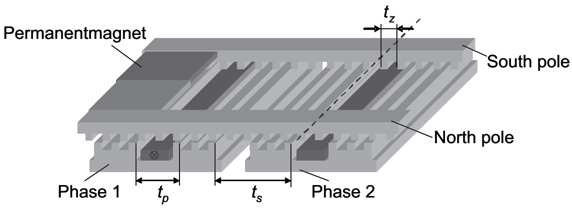

Fig. 1.6 Concept of a linear micro hybrid stepper motor

passive magnetic guidance. This basic idea has also been successfully applied to a rotating variable reluctance microstepper motor.

Another concept is the linear micro hybrid stepper motor (see Fig. 1.6). This motor is based on a variable reluctance (VR) stepper motor but equipped with permanentmagnets to increase the driving force.

As the simple VR motor is easier to fabricate than the hybrid one, additional prototypes have been created based on this concept. The VR motor requires the fabrication of microcoils and soft magnetic circuits. To overcome the normal forces between stator and traveler, an active magnetic guidance was developed. Based on this concept, the final prototype comprising contributions from all subprojects has been defined; the prototype includes an xy-nanopositioning stage comprising of four linear VR stepper motors controlled in the microstepping mode, magnetic and tribological guidance and xy-position sensors (Fig. 1.7).

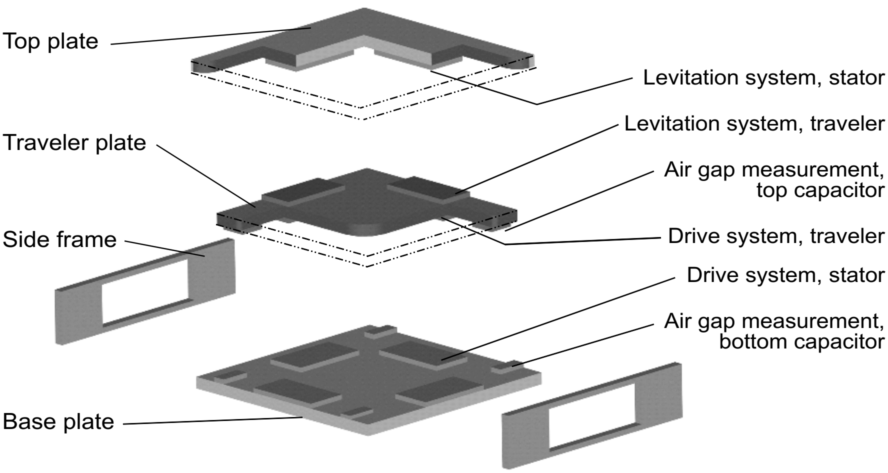

Fig. 1.7 Concept of an xy-nanopositioning stage

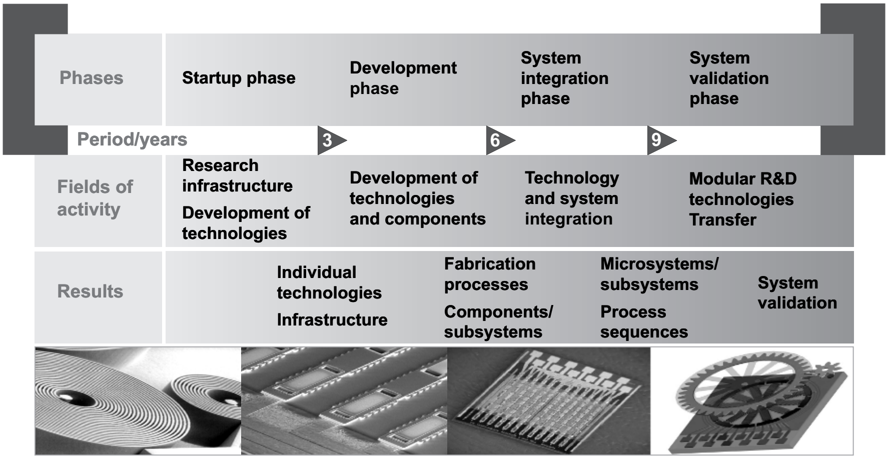

Fig. 1.8 Scientific development of the Collaborative Research Center

1.3 Scientific Development

The activities of the Collaborative Research Center comprised four three-year phases (see Fig. 1.8). During the startup phase, the necessary research infrastructure was established. Experimental equipment was installed and several technologies, such as UV depth lithography for the fabrication of microcoils and magnetic flux guiding structures, were developed and optimized.

In the development phase, the research activities were focused on the adaptation of the individual technologies developed during the startup phase to the fabrication of components of the magnetic micromotors. The actuators of the variable reluctance prototype micromotors have been manufactured, and the feasibility of the concepts has been demonstrated. By the end of the second phase, methods and processes for the design and manufacturing of components and subsystems of active microsystems have been made available.

During the system integration phase, the process technologies, including handling devices, assembly processes and the development of tribological layers, were combined to process sequences for the fabrication of magnetic micromotors. To assist with the design of active microsystems, simulation models were improved and extended to further prototype concepts, and a construction kit for microactuators and a software tool for the design of microparts were developed. Furthermore, control circuits, which accomplish continuous stepping of the micromotors, were developed and successfully tested.

The main purposes of the system validation phase were the integration of active guidance and measuring systems into the prototypes, the development of an xy-nanopositioning system, and the application of the technologies to other kinds of magnetic microactuators. Three additional projects were devoted to the transfer of selected technologies into industrial applications in close cooperation with industrial partners. This covers the development of a microvalve, a miniaturized precision assembly robot, and automated inspection methods for electronic production.

1.4 Outline

This book describes in detail the results developed within the Collaborative Research Center. First, the essential design tools and theory for magnetic microactuators are presented. The simulation of drive systems and concepts for position control of microactuators is investigated in Part I. The open and closed loop control algorithms that are discussed take into account the unique dynamic behavior and aspects of miniaturized systems.

Necessary methods for guides and measuring systems within active microsystems are discussed in Part II. This includes an investigation of the frictional and abrasive behavior as well as their reduction by applying appropriate protective layers. In conjunction with this, the integration of measuring systems into the actuator is presented. Production measuring techniques are used to measure the dimensions of the microsystems and their characteristics.

The development of fundamental manufacturing techniques for active microsystems is presented in Part III. This covers thin-film technologies such as coating, etching and lithography for the manufacturing of the functional components: guides for the magnetic flux, coil systems and isolation layers. Other micromachining processes such as drilling, milling, and grinding are explored in order to machine the conventional components.

Part IV presents solutions for the automated assembly process using new handling devices, sensor guidance, and joining technologies. Here, the influences of the tolerances of three-dimensional microparts and the behavior of these components on the assembly process are investigated.

Based on results from research models, Part V presents industrial solutions using microsystem technology for biomedical applications, new assembly devices, electronic production, and consumer electronics.

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