Application-Specific Piezoelectric Components: High Displacement in a Small Component Size

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Abstract

Multi-layer piezoelectric components have in recent years become a very effective solution for engineers looking for a high degree of precision and control in their micro-positioning applications. These engineers, once limited to standard, off-the-shelf components, now have at their disposal a range of very small actuating components that can be designed and produced to meet the exact performance parameters of their state-of-the-art applications. One of Noliac's customers approached the company with a challenge of producing very compact component meeting the high displacement given by a stacked actuator (SCMA) but at lower cost. In the following article, this project is outlined, where, working in close cooperation with the customer, a Ceramic Multi-layer Bending Ring (CMB-R) has been produced, delivering a displacent (stroke) equivalent to that of an actuator 25 times its size, with a cost structure making this very attractive for the industry.

Introduction

After years of research and development, piezoelectric actuators have evolved from infancy stage in the labs to mass-production industrial applications. Noliac, a well-known supplier of standard and customised low voltage multi-layer piezoelectric actuators, designs, develops and produces application-specific piezoelectric components meeting customers' exact requirements.

One of Noliac's customers recently approached the company with specific requirements for producing high stroke in a very small component size. Whereas actuators produce the necessary stroke, the component is sometimes too tall to be designed into applications, and further, produces a force that is often superfluous for the application. With its specialized technology processes and R&D resources, Noliac developed a Ring Bender Actuator that delivers the same stroke as a stacked actuator solution with a 25 times smaller height requirement.

In the following pages, the details of this successful project cooperation between Noliac and its customer are outlined. The aim of this project was to manufacture and develop a line of very compact piezoelectric actuators (thickness lower than 3mm) to replace a stacked actuator solution. The solution required a low driving voltage (≤60V), as well as fast response time, fine precision, low power consumption, and low electromagnetic interference. The solution also needed to deliver stroke performances that are not typically in the range of most common types of piezoelectric actuators: free strokes ranging from 20µm to 100µm. The blocking force for this customer application was defined as 50N.

The Process

Noliac executes each of its projects according to the Noliac Project Model (NPM), which is designed to facilitate a fully coordinated project between the customer and Noliac, to ensure that all technical and commercial goals of the project are met, and to facilitate a rapid and smooth transition from prototype to volume production. The NPM consists of a series of distinct phases, as shown in figure 1.

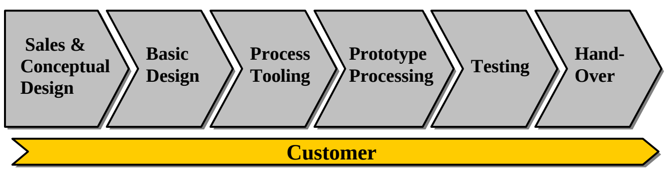

Figure 1: *The Noliac Project Model (NPM).*

The NPM first ensures a clear understanding of the project goals and enables the customer to monitor the progress at each stage of the project. Noliac engineers stay in close contact with the customer throughout all phases of the NPM to ensure that all parameters in a dynamic and changing world are met.

- The *"Sales and Conceptual Design"* phase includes defining the scope clearly, timeframe expectations, and financial objectives of the project. The deliverable in this phase is a contract including component specification, price and delivery time.
- In the *"Basic Design"* phase, the contract is translated into a project plan and aligned to specific activities. A detailed project plan is established and a Noliac technology team reviews the conceptual design. The technology team is comprised of experts in different fields and competencies. This phase also includes manufacturing of semi-manufactured articles for the final product.
- The *"Process Tooling"* phase is a review of the existing process tooling, designing of optimised production set-ups and parameters, including design and manufacturing of new process equipment and tooling.
- The *"Prototype Processing"* phase includes the manufacturing of prototypes, delivered in a number of distinct processes. The fast processing of the first samples (less than 6 weeks for such a project) is one of Noliac's important competencies. All of these processes are individually monitored to ensure a high quality product to the customer. Each process is optimised for the specific product and the parameters are stored for future productions, to ensure smooth transition to volume production. Furthermore, future plans are made more specific according to the market expectations based on the clients market study
- In the *"Testing"* phase, several tests are performed to approve the samples according to the specifications and requirements.
- Finally, the *"Hand Over"* phase takes place and the client will take over the project. The project is evaluated and feedback is collected.

Sales and Conceptual Design

Indeed, in the world of piezoelectric actuators, most of the components available are either ceramic multi-layer plate benders (CMB), ceramic multi-layer actuators (CMA) or stacked ceramic multi-layer actuators (SCMA) (see figure 2). Benders show typically large displacements (up to 2mm) with low blocking forces (up to 10N), whereas actuators provide large forces (up to 20KN) for relatively limited stroke (a few microns). For many applications, there is a strong need for very compact actuators providing a sizable displacement with sufficient force, essentially filling in the gap between benders and actuators.

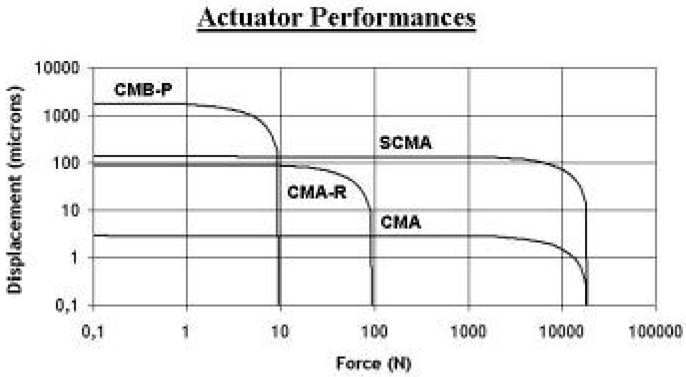

Figure 2: *Overview of piezoelectric actuator performances.*

Basic Design

Several concepts and principle actuators were explored. Piezoelectric actuators based on a magnification mechanism could have provided the necessary performances, but would not have addressed the size limitations (thickness lower than 3mm) and price target.

Noliac designed a new concept that leveraged the bender principle in the form of a ring, which features the maximum working capacity [1] (indeed the isotropic contraction of the piezoelectric ceramic is exploited advantageously orthogonally to the polarisation axis).

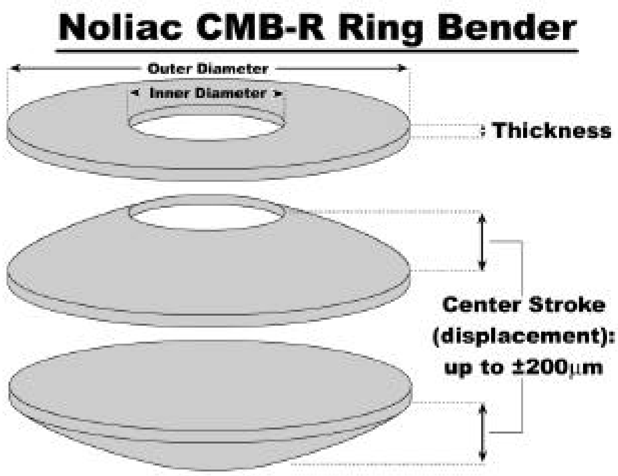

Figure 3: *Ring bender actuation principle.*

A piezoelectric ring bender (see figure 3) has a multi-layer structure [2] in which a number of thin electrodes are arranged. S2 (Pz29), a high strain PZT material and particularly suitable for static applications, was chosen as the actuator material for this investigation.

The electrical field the S2 is tested is currently3 KV/mm and, in order to keep the operating voltage within the practical limits imposed by the project requirements, the ring benders were designed with a ceramic layer thickness of 67µm so that the actuator requires 200V for full motion.

The internal electrodes, which are made of conductive metal paste was configured in three different sections depending on whether they were connected to ground, plus or minus of the power supply.

Each set of the internal electrodes extend horizontally, equally spaced from each other, have an area slightly smaller than a horizontal cross-section (for insulation purposes) and have extensions reaching one end of the circumference. These extensions (called external electrodes) are electrically connected together at one end by means of metallization.

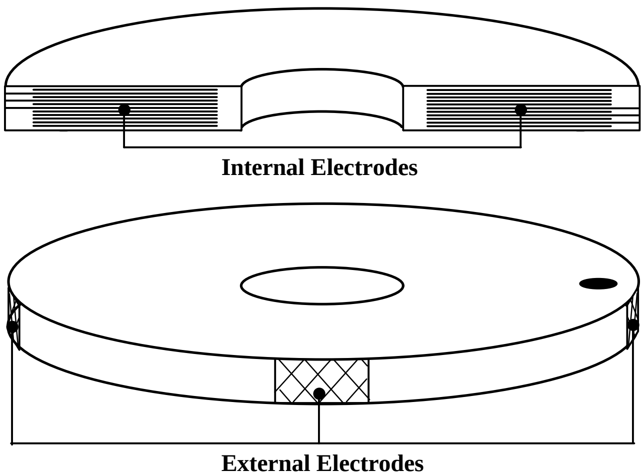

Figure 4: *Schematic presentation of a ring bender.*

The ring bender having the above shown structure operates as follows. When an appropriate voltage is applied to the external electrodes, the ceramic situated between the set of internal electrodes connected between ground and plus contracts in the radial direction of this region, while no such contraction occurs in the ceramic situated between the set of internal electrodes connected between the ground and the minus.

As a result, the ring generates a deformation as a whole to take a partly spherical shape as shown in Figure 3. The displacement at the edges of the inner diameter is entirely a vertical translation and can be used for actuating purposes.

Ring benders with various sizes were designed to span a wide range of performances and also so that properties and performances of ring benders could be tailored through geometrical design and material selection in future productions. For that purpose, ring benders with 3 different outer/inner diameters (20/4mm, 30/6 mm and 40/8mm) and thickness (0.67mm, 1.2mm and 1.8mm) were designed so that 9 different types of prototypes were manufactured.

Process Tooling and Prototype Processing

For manufacturing the prototypes, new tools specific to ring bender geometries were designed and manufactured (equipment for poling, new tools for the dicing etc.). With regards to the prototype processing, ring benders were manufactured using a piezoelectric ceramic material, which was tape-casted, printed with conductive metal paste as internal electrodes, stacked, laminated, burned out and sintered.

Then separate elements were diced and machined to its external dimensions, electroded and poled using conventional production techniques. The manufacturing process of multi-layer components is illustrated in Figure 5.

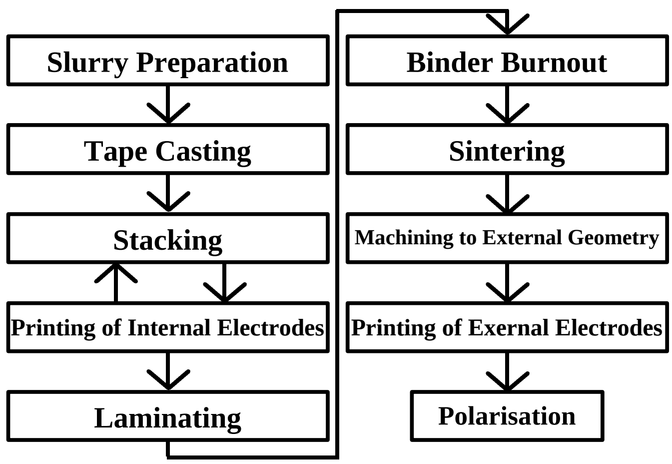

Figure 5: *Schematic presentation of the process used for production of Ceramic Multi-layer Bending Rings.*

Testing

The test equipment had to be suitable to perform accurate measurements. In order to get stroke versus forces curves, and so to have access to the free strokes and the blocking forces of the actuator, both stroke and forces were measured. The experimental set-up is shown in figure 7. The ring bender was mounted on a test stand where a 0.1µm resolution probe (with a special insert) measured displacements at the edges of the inner diameter. A 10^{-2} N resolution load cell measured forces applied on the ring.

Figure 6: *Experimental set up for piezoelectric ring benders.*

An example of the performed tests (stroke versus force curves) for ring benders of 30mm of diameter is illustrated in figure 7.

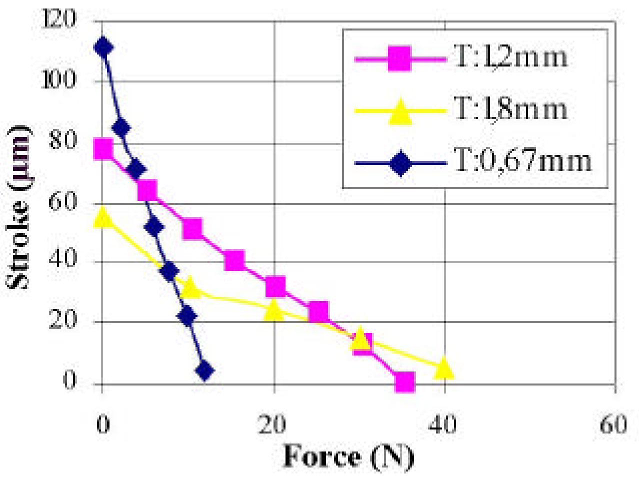

Figure 7: *Example of stroke versus force graph for ring benders of 30mm diameter.*

Table 1 illustrates the results for the different outer diameters and thickness' of the rings. As expected, the results show that ring benders feature performances in terms of stroke and blocking force that are not in the range of classical actuators.

The prototypes give free strokes ranging from 20µm up to 150µm and blocking forces up to 64N, offering remarkably high forces compared to CMB-P (plate benders) and a large displacement range compared to SCMA's (stacked actuators) in a much more compact design and this very attractive price performance characteristics.

ØD (mm)	20			30			40		
IØ (mm)	4			6			8		
T (mm)	0.67	1.2	1.75	0.67	1.2	1.75	0.67	1.2	1.75
Max. Center Stroke (µm)	51	31	23	102	72	54	150	125	96
Blocking Force (N)	8	17	26	11	33	45	12	40	64

Table 1: *Stroke and blocking force results.*

From these results, empirical formulas for free stroke and blocking force were established so that performances of ring benders can be tailored through geometrical design and material selection according to customer specifications.

For instance, free stroke and blocking force of ring benders with a free edge mounting, made in Pz29 and showing a ratio outer/inner diameter at least higher than 5 can be estimated by the following formulas:

$$S=0.089.T^{-0.71}.Ø^{2} \quad [µm]$$

$$F=0.667.T^{1.5}.Ø \quad [N]$$

With:

S: Free stroke [µm]
F: Blocking Force [N]
Ø: Outer diameter [mm]
T: Thickness [mm]

In addition, life time tests are currently being performed at Noliac to complete the study of this piezoelectric actuator. The first production lot of the CMB-R's have been tested 30 days long with a sinusoidal voltage of 200V at 50Hz (1.3E8 cycles). No breakdowns were observed in this time scale.

Hand-over

This project cooperation work has led to defining a new and innovative line of components. A key criterion of success is the ability to match customer and market requirements with the features and performances in order to meet a specific application area. Commitment and close communication during all phases from each of the project partners gives the best results. In the outlined project, working samples were delivered 8 weeks after the project was started, which allowed the partners to test their application design.

Conclusion

A new kind of extremely compact mid-range actuator, based on the bender principle has been designed and realised. The industrial potential of these new actuators is vast and ring benders could, for instance, advantageously replace stacked actuators in applications where no important forces are required. Indeed, Noliac's new Ring Bender is capable of replacing stacked actuators that typically require 25 times greater height to achieve the same displacement distance. In addition, the Noliac CMB-R can cost half of a stacked actuator solution that provides the same displacement.

The Noliac Ring Bender fills a distinct gap in the market, as the vast majority of applications currently using a stacked actuator do not require the high force typically available in this type of solution.

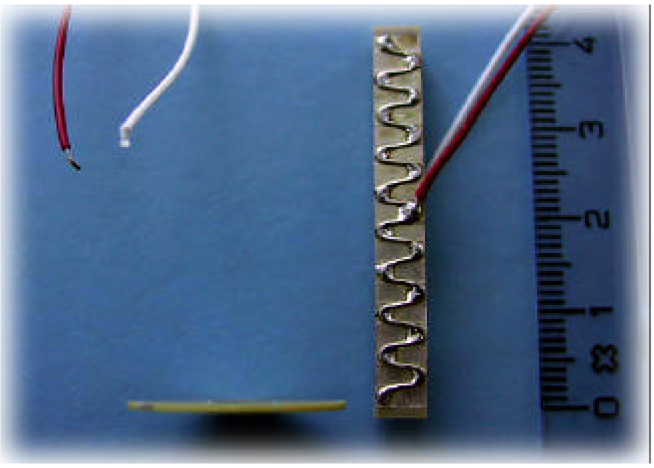

***Figure 8**: Ring bender of 20mm outer diameter and 0.7mm of thickness compared with a stack of 40mm long. Both actuators provide the same stroke (50µm of free stroke).*

Noliac's Ring Bender not only meets the need for high displacement in a much smaller unit size but also delivers a mid range stroke force, so that customers are not paying for superfluous performance. Noliac's new CMB-R will be a valuable solution in a wide range of micro-mechanical applications that require high displacement and do not require a great degree of force, such as fine tuning of a mirror in an optical device, or in the aligning of optical fibers in fiber optic component manufacturing. The unique combination of performance characteristics in Noliac's new Ring Bender greatly expands the range of applications that can make use of piezoelectric technology for micro-positioning.

References

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[3] B. Andersen, E. Ringgaard, L.S. Nielsen, Static and dynamic performance of stacked multiplayer actuators based on hard and soft PZT, Seventh International Conference on New Actuators, 2000, 423-426