A New Type of Mechanical Transformer with High Stroke Magnification Ratio

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Abstract:
The stacked PZT actuators are widely used in precision equipments. In this paper, a new type of mechanical magnifier incorporated with stacked PZT, which we brand it as MechaTrans® is proposed. It is a two-step magnification mechanism and is capable of performing precise and high speed linear motion. 30 types of MechaTrans® are commercialised. We have confirmed that the stroke is magnified up to sixteen hundred micrometers (1600μm), which is 60 times of the original stacked PZT stroke. Under a practical operation condition of an industrial application, the operated cycles of the MechaTrans® have already exceeded 1 billion cycles, and it is still operating in well condition. As another feature, MechaTrans® is capable of performing high speed linear motion. They have been successfully applied to several industrial applications. Besides, they are going to be applied to agriculture, consumer, and medical fields.

Keywords: stacked PZT actuator, flexure hinge structures, stroke magnification, amplification, MechaTrans®, magnification ratio

Introduction

In 1980's, one of the authors successfully commercialised piezoelectric impact printer head [1]. This was the world's first success in commercializing the stacked PZT and also the mechanical amplifier [2]. He also introduced the concept of energy transfer efficiency in designing the mechanical amplifier [3].

The term "flexure hinge structure" is widely used for the amplitude magnifying mechanism. While in the previous paper, one of the authors used the term "mechanical amplifier" instead of "flexure hinge structure" [3], [4]. In this paper, however, the term "mechanical transformer" is used instead of "mechanical amplifier" or "flexure hinge structure". The reason of the naming is that the mechanism does not amplify the energy but only magnify the amplitude or force, which is similar to an electrical transformer. On the same basis, we named the mechanical transformer incorporated with the stacked PZT as MechaTrans® and the MechaTrans® has been registered as a brand. In this sense, instead of the term "amplification", the term "magnification" is used here.

Based on the customer's requirements, the MechaTrans® is designed and developed by considering the following factors.

(1) Linear motion
(2) Stroke magnification ratio
(3) Energy transfer efficiency
(4) Response time
(5) Effective space utilization

By making use of the experiences of the piezoelectric printer head development, 30 types of MechaTrans® are developed.

The MechaTrans® have already been successfully applied to several industrial applications. They are going to be applied to agriculture, consumer, and medical fields.

Design and configuration of MechaTrans®

In order to achieve high stroke magnification ratio, it is necessary to choose a two-step magnification mechanism [5]. One of the key factors to achieve high energy transfer efficiency is to utilize the U shaped structure instead of L shaped structure as the base portion [1], [4], [5]. Compare to the L shaped structure, the U shaped structure have high stiffness to support the stacked PZT. Figure 1 shows previously developed impact printer element utilizing the U shaped structure as the base portion [3], [4], [5].

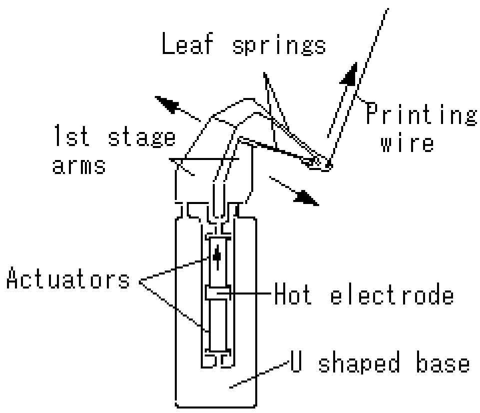

Fig.1 *Impact printer element [1], [4], [5]*

The impact printer element, however, actuates rotary motion instead of linear motion, because both the 1st step and the 2nd step magnification mechanism are based on the principle of leverage [4], [5]. In order to realize a linear motion, we introduced the buckling behaviour of the leaf springs as the 2nd step magnification mechanism, as shown in Fig.2. Furthermore, in order to have more effective space utilization, we folded the arm to the U shaped base side. Thus we finally get to the basic structure shown in Fig.3.

Figure 3 explains the actuation principle of MechaTrans®. When no voltage is applied to the stacked PZT, MechaTrans® stays still like the figure shown at right side. Holes, which are drilled on the U shaped base, are used to fasten the base rigidly. When a voltage is applied to the stacked PZT, the stacked PZT elongate, and a deformation is magnified through the mechanical transformer. This induces a magnified linear motion at the top of the MechaTrans® as shown in the left side.

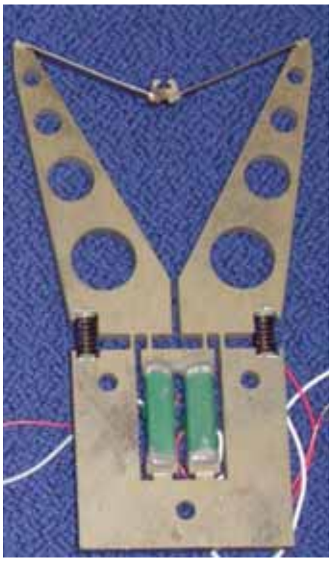

Fig. 2: *Actuation mechanism of MechaTrans®*

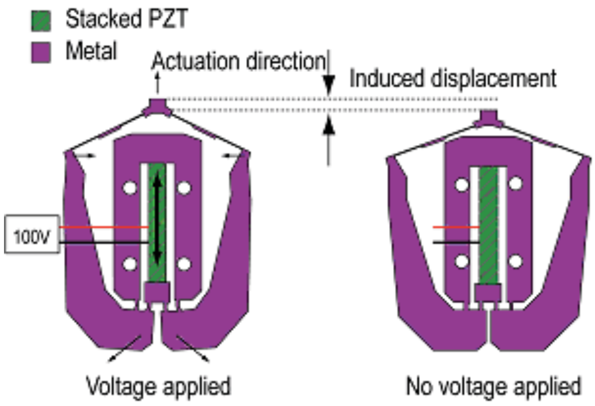

Fig. 3: *Actuation mechanism of MechaTrans®*

Performance of MechaTrans®

In order to correspond to various applications, a series of 30 types of the MechaTrans® with different performance as shown in Table 1 were designed and fabricated. In the series, the largest output stroke is 1600μm and the largest blocked force is 64N where the applied voltage to the stacked PZT is 100V. The Finite Element Method (FEM) was used as a tool to design the MechaTrans®. According to the calculated results, all the 30 types of MechaTrans® were fabricated and their output stroke measurements were conducted. The results show that the performances of these designs agree with the simulation results. Here, 3 types of the MechaTrans® (MTA05S400F9, MTA05S600F4 and MTA05S1600 as shown in Fig. 4, Fig. 5, Fig. 6) are introduced. The output stroke of the selected MechaTrans® are discussed later.

Table 1

Type	Size of stacked PZT[mm]	Stroke [μm]	Blocked force [N]	Stiffness [N/m]
MTA01S50F1	1.1x0.8x10	50	1.4	28
MTA01S100F0.6		100	0.6	6
MTA01S200F0.3		200	0.3	1.6
MTA02S50F5	2x3x5	50	5	74
MTA02S100F2		100	2	17
MTA02S200F1		200	1	4
MTA02S100F4	2x3x10	100	4	43
MTA02S200F2		200	2	11
MTA02S400F1		400	1	3
MTA02S200F4	2x3x20	200	4	17
MTA02S400F2		400	2	5
MTA02S600F1		600	1	1.5
MTA02S400F7	2x3x40	400	7	17
MTA02S600F5		600	5	8
MTA02S800F3		800	3	4
MTA05S100F13	5x5x10	100	13	132
MTA05S200F10		200	8	37
MTA05S400F3		400	3	7
MTA05S200F12	5x5x20	200	12	49
MTA05S400F9		400	8	21
MTA05S600F4		600	4	7
MTA05S400F26	5x5x40	400	27	57
MTA05S800F13		800	16	17
MTA05S1600F5		1600	5	3
MTA10S200F43	10x10x20	200	43	228
MTA10S400F29		400	28	71
MTA10S700F14		700	14	19
MTA10S400F74	10x10x40	400	64	148
MTA10S800F37		800	37	43
MTA10S1600F18		1600	18	11

Simulation and measurement results of the output stroke

As mentioned, FEM is used to simulate the output stroke of the MechaTrans®. In the simulation, the stacked PZT with dimension of 5x5x20mm (NEC TOKIN CORPORATION) is used for the MTA05S400F9 and the MTA05S600F4. In the case of the MTA05S1600F5, stacked PZT with dimension of 5x5x40mm (NEC TOKIN CORPORATION) is incorporated with it. For these 3 types, the applied voltage towards the stacked PZT was set at 100V as another boundary conditions. Based on the boundary conditions, the simulations were conducted.

The output stroke measurements for the MechaTrans® are conducted by using the apparatus shown in Fig. 7. The linear movement of the top of these MechaTrans ® are measured as the measurement target. Figure 8 shows an example of the stroke measurement results of a MechaTrans®. Table 2, 3 and 4 show the comparison of the simulation results and the output stroke measurement results. The simulation results recorded a good agreement with the measurement results for all the types.

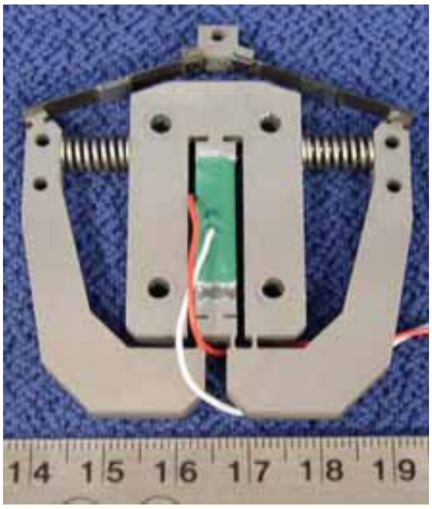

Fig. 4: *Fabrication of MTA05S400F9*

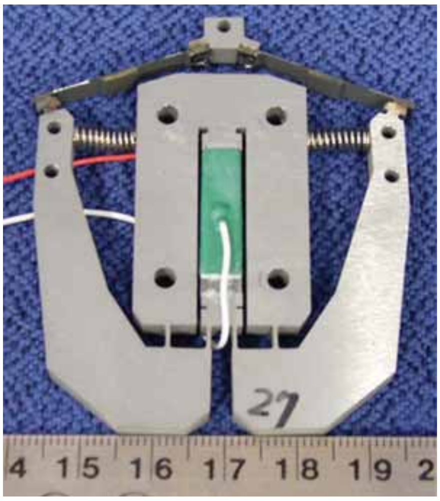

Fig. 5: *Fabrication of MTA05S600F4*

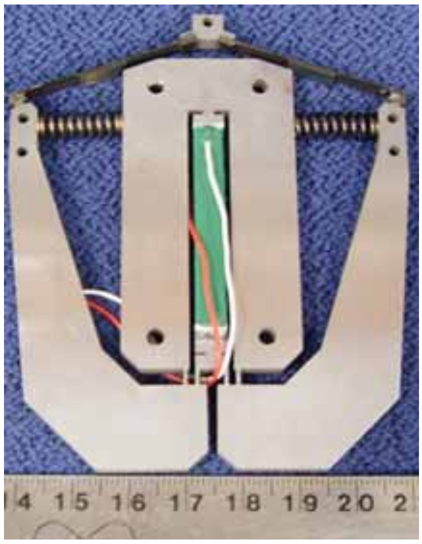

Fig. 6: *Fabrication of MTA05S1600F5*

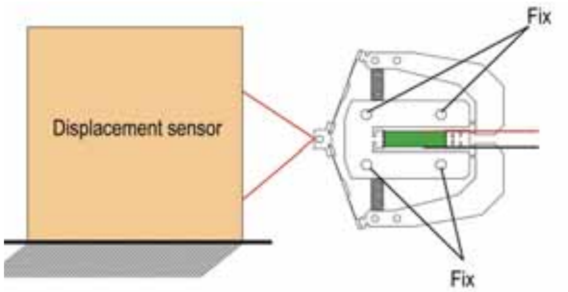

Fig.7: *Stroke measurement apparatus*

Table 2

MTA05S400F9	Simulation	Measurement
Stroke at 100V [μm]	402	410
Magnification ratio	35X	35X

Table 3

MTA05S600F4	Simulation	Measurement
Stroke at 100V [μm]	596	595
Magnification ratio	50X	50X

Table 4

MTA05S1600F5	Simulation	Measurement
Stroke at 100V [μm]	1678	1780
Magnification ratio	60X	63X

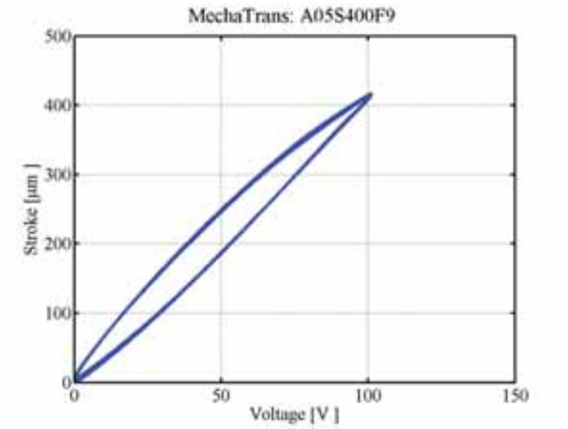

Fig. 8: *Applied voltage Vs Stroke of MTA05S400F9*

Reliability of MechaTrans®

A type of the MechaTrans® is already applied in some industrial applications. Under a practical operation condition of an industrial application, the operated cycles have already exceeded 1 billion cycles, and it is still operating in well condition. This shows the MechaTrans® is competent in durability, which is above 1 billion cycles.

Under high relative humidity environment such as above 60 RH%, the stacked PZT may be short circuit if it is applied with a DC voltage continuously for a long periods of time.

The default position of the top of MechaTrans® is temperature dependent. This is due to the different thermal expansion coefficient between the stacked PZT and the metal which is used as the body of the MechaTrans®. This can be overcome by choosing a metal with an appropriate thermal expansion coefficient.

The output stroke of the MechaTrans® shows a hysteresis behaviour like Fig. 8. This behaviour is unavoidable if the present stacked PZT is used. If the MechaTrans® is to apply in the applications where precise positioning is concern, a feedback loop with displacement sensor is necessary.

Applications

Many applications developments utilizing the MechaTrans® are in progress. In these developments, the MechaTrans® are recognised due to the following reasons.

①High speed operation

The MechaTrans® outbreaks the speeding up limitation of the actuator that utilizing the electromagnetic force.

②High energy transfer efficiency

MechaTrans® stands an edge over other actuator in the electro-mechanical conversion efficiency.

③Slimness

Unlike other actuators, in spite of the output performance, MechaTrans® are slim enough to be stacked up. As a result, they can be applied in applications that need severe pitch size.

Conclusion

A new type of mechanical transformer with high stroke magnification ratio is introduced. The mechanical transformer incorporated with stacked PZT were successfully developed and was branded as MechaTrans®. In order to correspond to various applications, a series of 30 types of the MechaTrans® with different performance as shown in Table 1 were successfully commercialised. A type of the MechaTrans® is already applied in some industrial applications and has recorded more than 1 billion operated cycles.

In this paper, the magnification ratio of the MechaTrans® introduced here are 35X, 50X and 60X. With our experience, we manage to tailor the magnification ratio, according to customers' requirement, for example above 100X. Furthermore, in stead of the output stroke of the MechaTrans®, we do manage to tailor blocked force or stiffness instead of the stroke.

Acknowledgements

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