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Vibration Reduction module with Flexure Springs for Personal Tools

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***Abstract*—**In the various working field, vibration may cause injurious to human body. Especially, in case of the vibration which is constantly and repeatedly transferred to the human. That gives serious physical problem, so called, Reynaud phenomenon. In this paper, we propose a vibration transmissibility reduction module with flexure mechanism for personal tools. At first, we select a target personal tool, grass cutter, and measure the level of vibration transmissibility on the hand. And then, we develop the concept design of the module that has stiffness for reduction the vibration transmissibility more than 20%, where the vibration transmissibility is measured with an accelerometer. In addition, the vibration reduction can be enhanced when the interior gap between inner and outer body is filled with silicone gel. This will be verified by the further experiment.

***Keywords*—**Flexure spring, Tool engineering, Vibration damping.

I. Introduction

GENERALLY the personal tool is an instrument handled by a human. The type and use of personal tools become various because of mechanization of work, requirement of convenience, increase of their industrial application and so on. According to the tendency, the tool industry has grown and the various commercial products of the tools have been developed. But, several kind of the tools have problem of vibration. The vibration of the tool not only weakens its performance and reliability but also do harm to the worker. For instance, the vibration may cause Raynaud phenomenon which is a kind of obstruction of blood circulation [1].

In this paper, we propose a vibration reduction module and perform an experiment to evaluate its performance. The design of proposed device can be applied to various personal tools. In this work, we select a target tool with serious vibration level but wide use. A selected personal tool is a grass cutter, Fig. 1, actuated by an internal combustion engine. The engine causes a serious vibration that transfer to worker's body through a tool's shaft. We focus that reduction of the tool shaft's vibration which is gripped by worker's hand.

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Fig. 1 Grass cutter and the name of each part

II. Design

A. Concept Design

The proposed module was considered as a vibration isolator on a rigid base [2]. The vibrating mass rests on the flexible mechanism, that system can be ideal modeling as shown in Fig. 2. In this case, the force transmissibility and transmission ratio are calculated by (1) and (2). In this paper, we target the module that would be composed only flexural spring without damper.

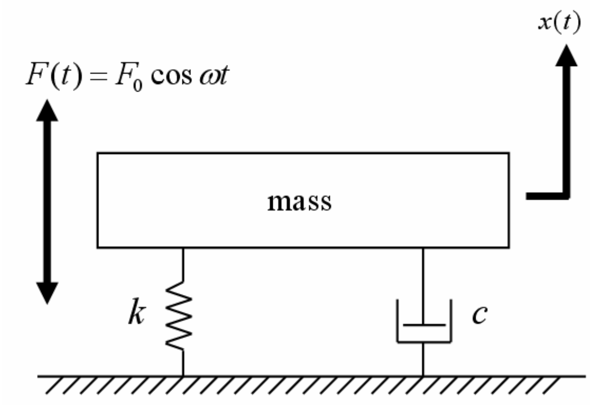

Fig. 2 Ideal modeling of 1 DOF spring-damper system

In those equations, where T_r denotes the transmission ratio, ω is the excitation frequency by the tool, ω_n is the natural frequency of the system. The target value, stiffness k, is calculated from ω_n.

$$F_t = \left[(kx)^2 + \left(c\dot{x} \right)^2 \right]^{1/2} = X\sqrt{k^2 + \omega^2 c^2} \\ = \frac{F_0}{\sqrt{\left(k - m\omega^2\right)^2 + \omega^2 c^2}} \tag{1}$$

$$T_r = \frac{F_t}{F_0} = \left\{ \frac{1 + \left(2\zeta \frac{\omega}{\omega_n} \right)^2}{\left[1 - \left(\frac{\omega}{\omega_n} \right)^2 \right]^2 + \left(2\zeta \frac{\omega}{\omega_n} \right)^2} \right\}^{1/2} \tag{2}$$

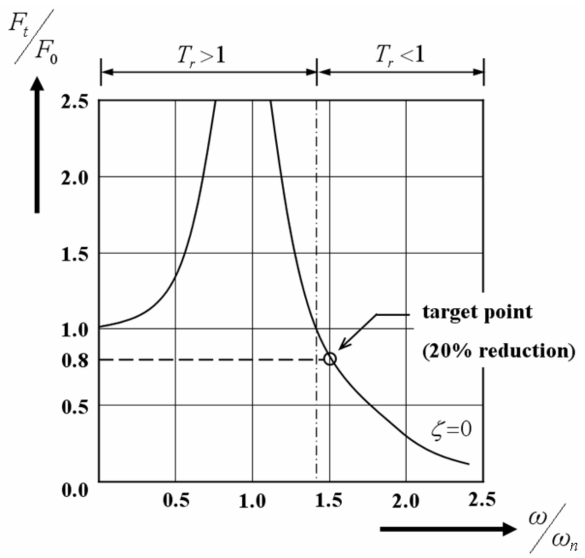

Fig. 3 The graph of versus transmissibility (T_r) and target point

We targeted the reduction ratio, 20%, of force transmissibility using the graph of versus transmissibility (T_r) as shown in Fig. 3. In the case that the excitation frequency (ω) over the natural frequency of the system (ω_n) is more than 1.414, the force transmissibility can be reduced. Accordingly, we designed the stiffness (k) of the module.

To reduce the force transmissibility, we propose the module as shown in Fig. 4. The module is implemented with three flexure leaf spring. Each section has tri-symmetry and overall design is symmetric. The inner cylinder is mounted on the tool's shaft and the outer cylinder connected by leaf spring as gripped by worker's hand. When the shaft vibrates, the module reduces the vibration transmissibility by the elastic deformation of leaf springs as shown in Fig. 5. And the module has five degree of freedom by adding the two set of notch hinge.

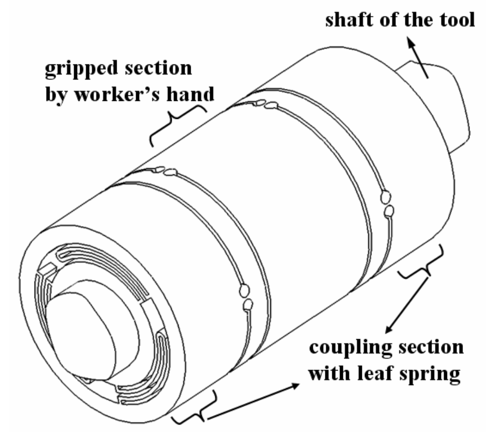

Fig. 4 Concept design of the proposed module.

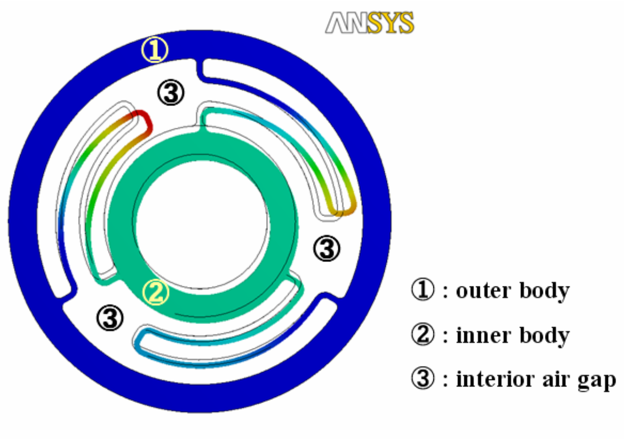

Fig. 5 Elastic deformation simulation result of the module.

B. Optimal Design

To design the vibratory force transmissibility reduction module with flexure mechanism, we should consider the many design factors.

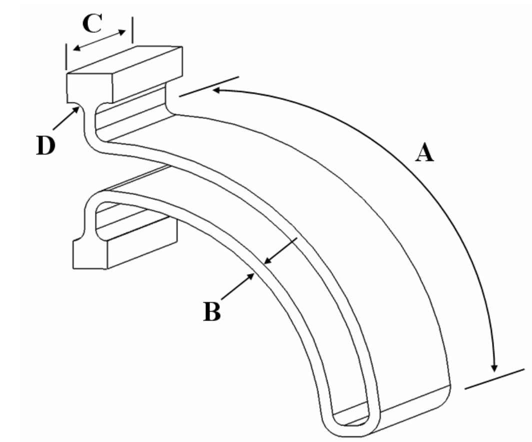

Fig. 6 Main design factors of the proposed flexure leaf spring.

Above all we consider the maximum stress that caused by vibration and the natural frequency of the module that have an effect on the durability and the reliability.

In this paper, for design optimization to enhance the performance of the module, main design factors, Fig. 6, are categorized into the control factors as shown in Table I. All control factors are the design parameters form the leaf spring. Because performance of the module is affected by leaf spring level, as above mentioned, the proposed module is configured with three leaf springs with the same shape.

The material of the module was selected as Duralumin because of its light weight and high stiffness. Table II shows the evaluation criteria according to control factor, noise factor, and each level change. Table of orthogonal array was organized based on Table I. Three-dimensional finite element analysis (FEA) for evaluating according to each factor and level was conducted. Signal to noise ratio (S/N ratio) can be obtained by using the result of each analysis and number of experiment. As a result, the optimal design was found out.

TABLE I
FACTORS AND LEVELS FOR OPTIMAL DESIGN USING TAGUCHI METHOD

Sort		Factor	Level 1	Level 2	Level 3	Level 4
Control factor	A	Length of leaf spring [mm]	31.0	32.4	33.8	35.2
	B	Thickness of leaf spring [mm]	0.8	1.0	1.2	1.4
	C	Height of leaf spring [mm]	10	15	20	25
	D	Radius of fillet [mm]	0.5	1.0	1.5	2.0
Noise factor	P	Fabrication error of leaf spring thickness	good	Bad	good : ideal case bad : actual case	
	Q	Assembly error between flexure mechanism and tool shaft	good	bad		

TABLE II
EVALUATION CRITERIA

NO.	EVALUATED CHARACTERISTICS	TYPE
1	FORCE TRANSMISSIBILITY REDUCTION RATIO	LARGER-THE-BETTER
2	MAXIMUM STRESS	SMALL-THE-BETTER
3	1ST RESONANCE FREQUENCY	NOMINAL-THE-BETTER

The simulation result with optimal design shows that the stiffness of module is 356 kN/m. In this case, theoretically, the module reduces the force transmissibility from tool shaft to worker grip approximately 20%. And the result of maximum stress also satisfies the condition of yield strength of material. To verify this simulation result, we fabricate the module and experiment about the performance.

III. EXPERIMENTS

A. Performance Test of the Module

The force transmissibility reduction module was fabricated by wire electro discharge machining. The fabricated part is mounted on the shaft of a grass cutter tool. The setup of experiments is shown in Fig. 7. The characteristics of this module, such as force transmissibility reduction, were measured by wireless ANYLOGGERTM accelerometer with measurement accuracy 0.1% and 1 kHz real time sampling rate.

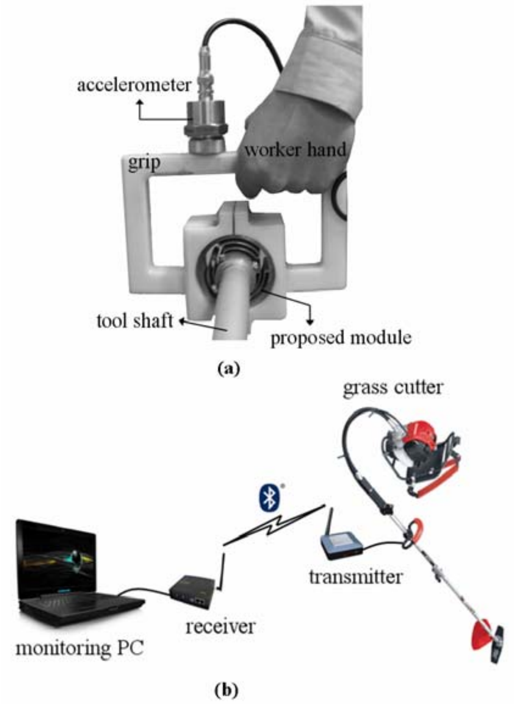

Fig. 7 Experiment setup: (a) Accelerometer setup with the module and tool, (b) Schematic of data acquisition

This wireless instrument works by Bluetooth communication between the transmitter mounted on the tool shaft with the proposed module and the data acquisition receiver connected with monitoring PC. To consider the reality of experiment, the transmitter is mounted on the shaft grip which also griped by worker's hand. The real time acquired data is displayed as time versus acceleration. Therefore we can measure the vibration transmissibility reduction ratio.

The Fig. 8 shows the result of experiment. Be-cause the accelerometer records the data as real time, we sampled them to analyze. As a result graph of data sampling, the amplitude of vibration transmissibility decrease more than 20% from 11 G without the module to 7 G with the module. (The unit G means the numbers on axis are to be multiplied by the gravitational acceleration.) The experiment result shows that the error compared to simulation result is within 5%.

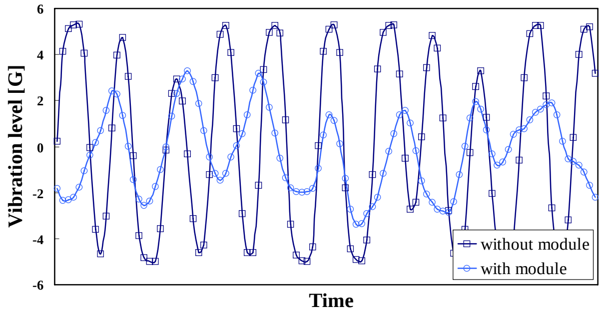

Fig. 8 Experiment result of vibration transmissibility reduction by the proposed module

B. Applying Damping with Viscoelasticity Gel

The proposed module was fabricated without damping material. Hence, we applied the viscoelasticy gel for more force transmissibility reduction. In this case, the stiffness of the module would be larger than before. But large internal damping of viscoelastic material can compensate that, furthermore, it can help to reduce the force transmissibility and prevent the unnecessary deflection of leaf spring by the shaft weight.

We filled the interior gap with commercial viscoelastic commercial silicone gel of dynamic viscosity 430 cp [3]. The selected gel was considered as not only minimum elasticity but also maximum viscosity.

IV. Discussion & Conclusion

This paper describes the design, fabrication, and experimental results of vibration transmissibility reduction module. The module implemented by three symmetric flexural leaf springs reduces the vibration transmissibility more than 20%. And we conducted additional experiment as the interior of module was filled with viscoelastic silicone gel for more reduction of force transmissibility. Compare with many other vibration reduction mechanisms, our proposed module provides structural simplicity and generality. Besides, by ease to implementation with flexure mechanism, this module can be applied to not only various personal tools but also, furthermore, industrial fields which have problems form vibration.

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