

# Development of the SE15A Gear-shaping Machine with Dry Cutting and High-speed Strokes



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Mitsubishi Heavy Industries, Ltd. (MHI) has developed the "E series" gear-cutting machines, designed for dry cutting and high productivity. While the lineup of GE series hobbing machines has already been completed, the SE25A is the only gear-shaping machine of this type that is currently available from MHI. Therefore, in an attempt to enhance this product area, we have developed the SE15A, a compact gear shaper that provides excellent high-speed cutting of small gears, especially the kind used in motorcycles. The SE15A attains high-efficiency gear shaping by suppressing the vibrations that are likely to occur at high stroke speeds, and also offers machine layouts that facilitate its introduction into mass production lines, as well as dry cutting, to further improve the productivity of small gear shaping.

## 1. Introduction

In gear cutting, especially gear hobbing, the trend is toward high-speed and high-productivity systems. One such product is the complete dry hobbing system developed by Mitsubishi Heavy Industries, Ltd. (MHI), which was the first of its kind. In recent years, to reduce the size and cost of the body and gear train, automobile and motorcycle manufacturers (the two main users of gear cutting machines) have tended to integrate two or more parts into a single complex part. Examples of such parts are shoulder gears and internal gears. However, these complex parts cannot be cut with a hobbing machine; a gear-shaping machine must be used instead. For this reason, many gear manufacturers have come to expect the same high speed and productivity in gear shapers as in hobbing machines.

In this paper, we describe the development of the Mitsubishi SE15A gear-shaping machine, a compact gear shaper that provides excellent high-speed cutting of small gears (especially those used in motorcycles) to address this need.

## 2. Development objectives

### 2.1 Target of the SE15A

The SE15A gear-shaping machine is designed for mass production of gears with a small diameter or face width, typically those used in motorcycles. **Figure 1** shows a typical gear-shaping workpiece (small shoulder gear) that must be cut using a gear shaper instead of a hobbing machine because of the shouldered part below the gear. The primary specifications of the SE15A are listed in **Table 1**. In developing this machine, we investigated the following three priority issues: (1) high-speed strokes with reduced vibration for parts having a small face width, (2) selectable machine layout in accordance with the configuration of the manufacturing line, and (3) support for dry cutting that is optimized for gear shaping.

### 2.2 High-speed strokes with reduced vibration for parts having a small face width

Small gears often have both a small diameter and a small face width. Therefore, in order to attain the high cutting speed of 130 m/min required for dry cutting, the spindle stroke speed must be adequate. Since gear-shaping machines utilize the vertical stroke motion of the spindle to cut the workpiece, vibrations are unavoidable. To suppress these vibrations, the SE15A gear-shaping machine employs a newly designed shaft called "Silent Shaft" in the gearbox.

**Table 1 Primary specifications of the SE15A dry-cut gear-shaping machine****Figure 1**  
Typical gear-shaping workpiece

Max. workpiece diameter (mm)	$\phi$ 150 for external gears, $\phi$ 60 + cutter PCD for internal gears	
Max. workpiece face width (mm)	32	
Max. spindle stroke width (mm)	40	
Max. spindle stroke speed (str/min)	400 to 2 000	
Max. cutting speed (m/min)	130	
Width (m)	(Type I) 1.78	(Type II) 2.68
Depth (m)	2.41	1.71 (1.28 at narrowest point)
Area (m <sup>2</sup> )	4.29	4.58
Height (m)	2.72	
Main motor output (kW)	7.5	
Approximate machine mass (kg)	5 500	

### 2.3 Selectable machine layout in accordance with the manufacturing line configuration

Mitsubishi E series gear-cutting machines offer two types of standard machine layouts, as shown in **Figure 2**. Each of these layouts has the following characteristics.

Type I supports the loading and unloading of the workpiece at the front of the machine. The workpiece is loaded directly onto (or unloaded directly from) the table by an operator or robot. The front door offers a wide opening and a short access distance to the center of the table for ease of operation.

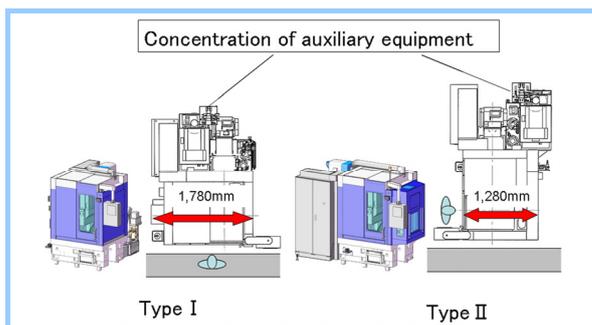
Type II supports the loading and unloading of the workpiece at the right side of the machine. The workpiece is loaded into (or unloaded from) the machine by an operator or gantry loader, and then placed on the table for gear shaping by the ring loader gripper attached to the counter-column. The right side of the machine, which provides the loading entrance for the workpiece, is made narrow to reduce the length of the manufacturing line and secure a sufficient workspace.

Both types utilize a design in which auxiliary equipment is concentrated opposite to the workpiece loading side for ease of maintenance. Since the target workpiece is small and the cycle time correspondingly short, the Type II SE15A gear-shaping machine employs an equipment arrangement that results in a particularly narrow workpiece loading side, making it well suited to mass production lines (**Figure 2**).

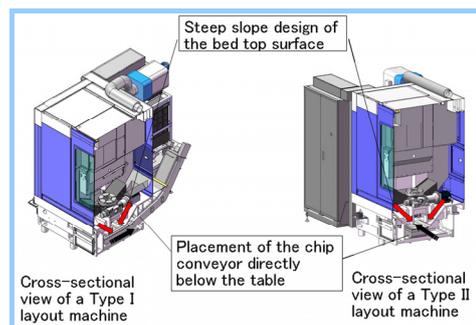
### 2.4 Support for dry cutting that is optimized for gear shaping

In order to attain perfect dry cutting, painstaking countermeasures for chip removal are required. For this purpose, the E series gear-cutting machines have adopted chip covers and a steep slope design to prevent the accumulation of chips in the machine. The chips generated during shaping are immediately collected and discharged from the machine by the chip conveyor placed directly below the cutting point to minimize thermal deformation caused by heat transmitted from the chips to the machine body. In addition, the design of the SE15A gear-shaping machine takes into account the following two points.

- (1) A wide chip conveyor is placed directly below the table to remove chips from the center of the table during internal gear shaping, which is specific to gear-shaping machines.
- (2) The chip conveyor can be placed parallel to either the width or depth of the machine to obtain a narrow loading entrance.

**Figure 2** Two types of machine layouts

Two types of machine layouts are offered:  
Type I supports front loading/unloading and  
Type II supports loading/unloading from the right side.

**Figure 3** Support for dry cutting

The direction of the chip conveyor placement varies in accordance with the layout type.

### 3. Factors that prevent high-speed strokes and our solution to the problem

#### 3.1 Vibration factors in a gear-shaping machine

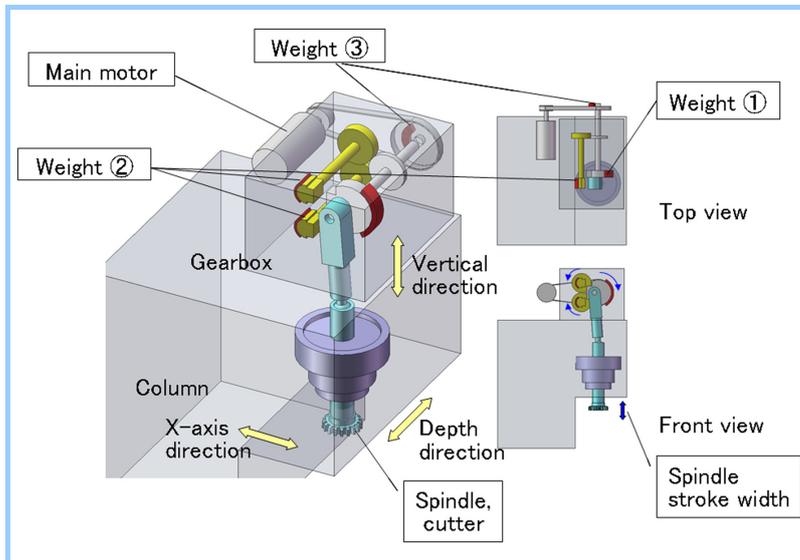
In a gear-shaping machine, the rotational motion of the main motor is converted via a crank mechanism into the linear motion of the spindle. To reduce the inertial force generated by the vertical motion of the spindle, the balance weight ① is attached to the opposite end of the crank pin. However, the balance weight ① also has a rotational motion, and hence in addition to reducing the inertial force in the vertical direction, it also generates an unwanted inertial force in the horizontal (X-axis) direction.

Thus, this method is relatively ineffective for vibration reduction. Moreover, it is difficult to place the spindle and the balance weight ① on the same plane due to the differing thicknesses of these parts, and this may result in a moment force. Because these inertial forces (which produce vibrations) become larger as the spindle stroke speed increases, gear shaping at high stroke speeds may cause the machine body to vibrate, possibly leading to auxiliary equipment failure and, in some cases, reduced machining accuracy.

As a solution to this problem, a new Silent Shaft design has been adopted.

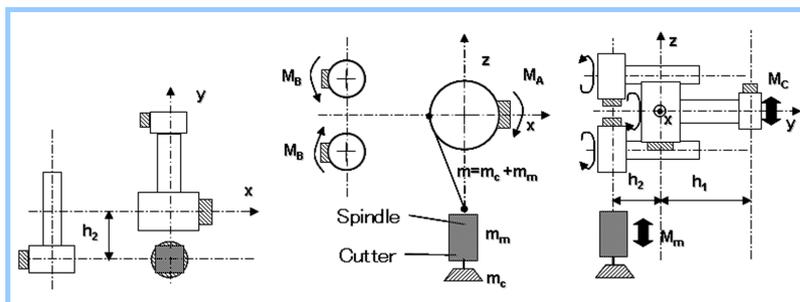
#### 3.2 The new Silent Shaft design (patent pending)

**Figure 4** illustrates the new Silent Shaft design employed in the SE15A gear-shaping machine. Two balance shafts are added in the gearbox, each with a balance weight ② to reduce the inertial force generated by balance weight ① in the horizontal (X-axis) direction. The balance weights ② are attached to two shafts that rotate in opposite directions to mutually counterbalance the vertical inertial forces generated. This design enables the use of balance weight ① to counterbalance most of the inertial force caused by the vertical stroking motion of the spindle, since the increased horizontal inertial force produced by balance weight ① does not pose any problems. In addition, a balance weight ③ is placed so that the inertial forces generated by the spindle and the other balance weights are compensated for in the depth (Y-axis) direction. On the basis of this design, we modeled the spindle system as illustrated in **Figure 5**, and determined the optimal placement and mass of each balance weight.



**Figure 4 New Silent Shaft design**

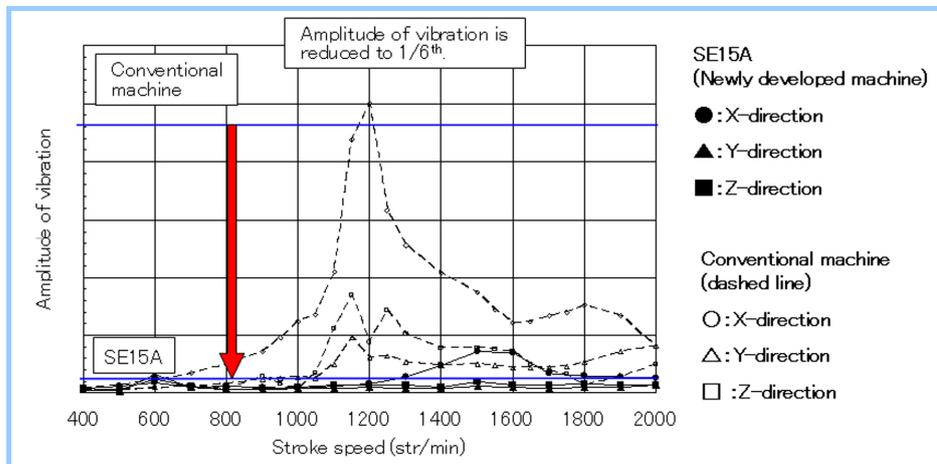
Vibration is suppressed by the multiple balance weights placed in optimal positions.



**Figure 5 Shafts and vibration analysis**

A schematic of the main spindle system.

**Figure 6** shows the results of vibration measurements conducted to verify the effectiveness of the new Silent Shaft design with balance weights. According to the graph, the amplitude of vibration in the X-, Y-, and Z-directions remained at a low level throughout the entire range of spindle speeds. It was reduced to approximately 1/6<sup>th</sup> the amplitude of vibration of conventional machines. This enables stable gear shaping at high spindle stroke speeds with minimal vibration, even when the workpiece has a small face width.



**Figure 6 Amplitude of vibration caused by a stroking spindle**

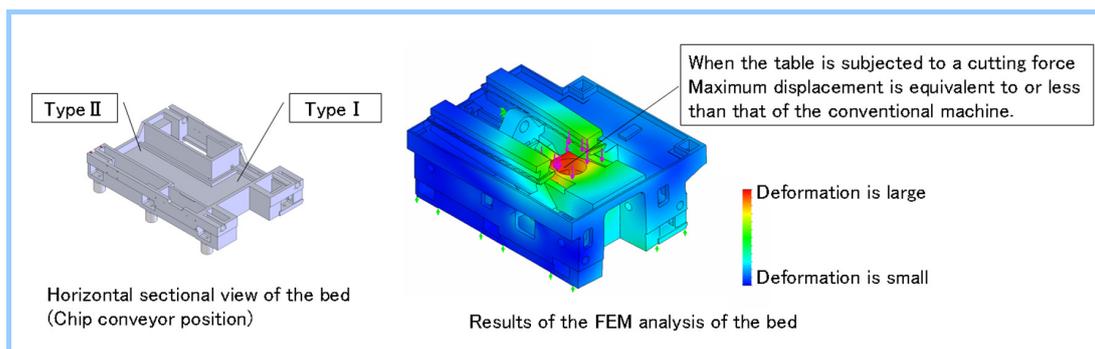
The maximum amplitude of vibration is reduced to 1/6<sup>th</sup> that of conventional machines.

#### 4. Simultaneous resolution of floor space reduction and rigidity issues

- (1) Two types of standard machine layouts are offered, depending on the configuration of the manufacturing line.
- (2) The chip conveyor is placed directly below the table to facilitate the handling of chips (in dry shaping) and the discharge of chips (in internal gear shaping).

To resolve the two issues of floor space reduction and rigidity simultaneously, it is necessary to provide sufficient space to allow placement of the chip conveyor parallel to either the width or the depth, and at the same time secure the rigidity of the bed. Although similar designs were considered in the past, it was difficult to secure the rigidity, and thus a layout permitting the longitudinal placement of the chip conveyor was infeasible.

To resolve this issue, FEM analysis was used throughout the design phase of the fundamental bed structure to secure space for the chip conveyor before determining the placement of the main ribs. At the same time, we also considered other requirements for the bed, such as the handling of chips in the machining area and enlargement of the maintenance window at the bottom of the bed, in order to achieve both floor space reduction and a level of rigidity equal to or greater than that of conventional machines (**Figure 7**). Furthermore, we concentrated the auxiliary equipment near the chip conveyor to minimize the installation area and facilitate periodic maintenance, such as oil replenishing. Attaching the auxiliary equipment to the machine body also allows the customer to move the machine as a unit during factory layout changes.



**Figure 7 Results of the bed rigidity analysis**

The internal construction of the bed and the results of FEM analysis

## 5. Machining example

**Figure 8** presents an example of workpiece shaping using the SE15A gear-shaping machine. The cycle time for this workpiece (Figure 1) was approximately 40 seconds with a conventional machine, but was reduced to 30 seconds (including the workpiece loading time using the ring loader) by the high-speed strokes and rigidity of the new machine. The SE15A exhibited improved cutting efficiency, with a cutting speed of 1.3 times that of the conventional machine, and 75% of the cycle time. Vibration was suppressed to a low level at high spindle stroke speeds, and the resulting machining accuracy was JIS N7-grade.

An example of continuous shaping using the SE15A gear-shaping machine is shown in **Figure 10**. Because of the quick discharge of chips during dry cutting, thermal deformation is kept at a low level, and the sector span is stabilized. The SE15A also provides the same degree of stability in continuous wet shaping under the same cutting conditions.

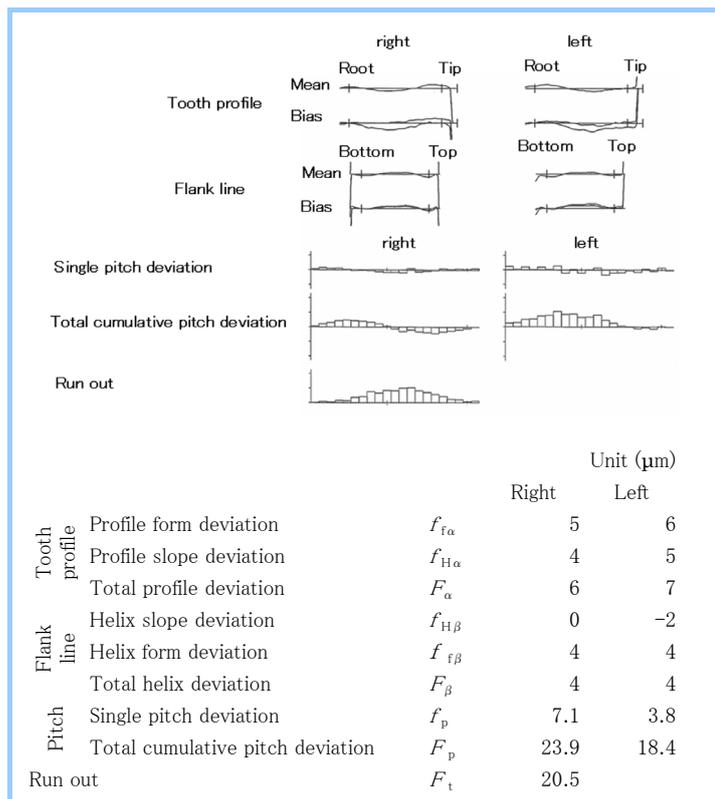
■ Cutting conditions for the conventional machine				Workpiece specifications	
Cutter specifications		Cutting conditions: double cutting (roughing/finishing)		Module (mm)	1.75
Outside diameter (mm)	φ 200.88	Spindle stroke speed (str/mm)	1 100/1 500	Number of teeth	21
Cutting edge width (mm)	30	Cutting speed (m/min)	48.4/66	Pressure angle (°)	20
Material	High-speed steel (MAC B)	Circumferential feed (mm/str)	2.749/0.55	Helix angle	Spur
Coating	PVD	Radial feed (mm/str)	0.017/0.007	Outside diameter (mm)	φ 41.2
		Depth of infeed (mm)	3.66/0.2	Face width (mm)	10
		Coolant	Wet	Material	SCM415
		Cycle time (s)	40.2		

■ Cutting conditions for the SE15A					
Cutter specifications		Cutting conditions: double cutting (roughing/finishing)			
Outside diameter (mm)	φ 200.88	Spindle stroke speed (str/min)	2 000/2 000	→ 30% increase compared with the conventional machine	
Cutting edge width (mm)	30	Cutting speed (m/min)	88/88		
Material	High-speed steel (MAC S)	Circumferential feed (mm/str)	2.741/1.1		
Coating	Super Dry III	Radial feed (mm/str)	0.015/0.015		
		Depth of infeed (mm)	3.66/0.2		
		Coolant	Complete dry		
		Cycle time (s)	30	→ 25% decrease compared with the conventional machine	

**Figure 8 Comparison of cutting conditions and cycle time**

The cutting speed for finishing is 1.3 times higher and the cycle time is 75% as long.



**Figure 9 Machining example**  
Gear shaping accuracy during complete dry cutting

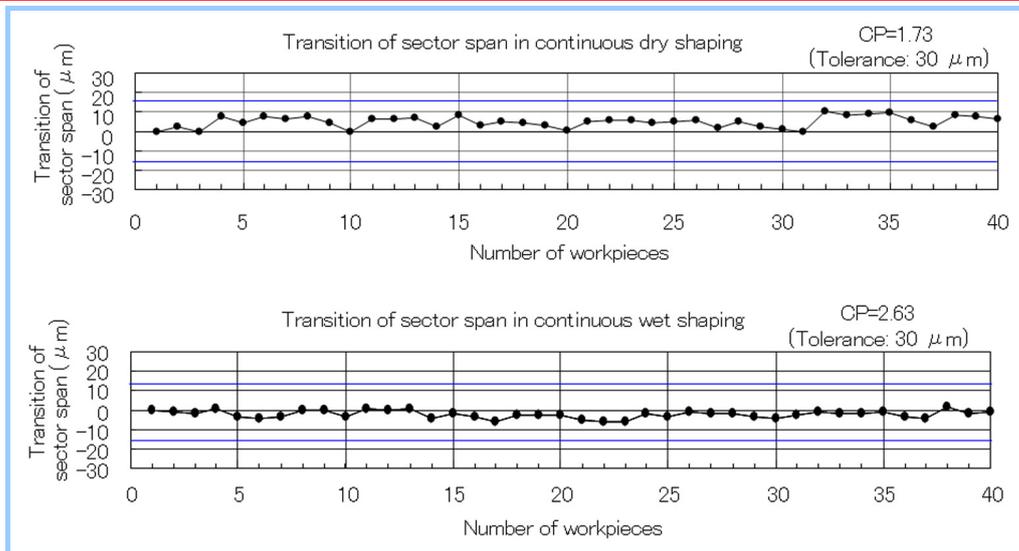


Figure 10 Transition of the sector span during continuous dry/wet shaping

## 6. Conclusion

The development of the SE15A gear-shaping machine, featuring high spindle strokes and mass production, completes the lineup of the compact "E series" gear-cutting machines, targeted for the automotive and motorcycle industry. This enables us to offer customers a full range of products incorporating the E-series concept, from hobbing machines, gear-shaping machines, gear-shaving machines, and gear-grinding machines to cylindrical grinding machines. Moreover, MHI is the only manufacturer in Japan that provides both gear-cutting machines and tools, and has also developed Super Dry III coated pinion cutters, along with the SE15A. With these advantages, we will continue to offer value-added gear cutting to our customers in the future.

## References

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