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ANALYSIS OF CHIP FORMATION AND ITS EFFECT ON TOOL WEAR AND SURFACE FINISH IN HARD TURNING

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Abstract: In this study, the hard turning is done to optimize cutting conditions for minimizing surface roughness, to analyze CBN cutting tool flank wear and it includes chip morphology. Hard turning has been done on AISI 4340 by CBN tool with the cutting speed range 31, 42 and 63 (m/min) and depth of cut are 0.5, 0.4 and 0.3 (mm). Statistical method like Taguchi, Regression and ANOVA have been applied and Prediction Equations of surface roughness and flank wear from regression analysis are found and validated by using experimental results. It is related to chip morphology; means different shapes of the chip produced during various cutting conditions and their effects on surface finish from the various types of chips. Among the various types of chips the C-type radii chip shows minimum surface finish during hard turning.
Keywords: Hard turning, ANOVA, chip morphology, AISI 4340.

I. INTRODUCTION

Hard turning is a developing technology that offers many potential benefits compared to grinding, which remains the standard finishing process for critical hardened surfaces. Hard turning is defined as the process of single point cutting of part/ pieces that have hardness above rc 45. It offers many potential benefits compared to grinding, which remains the standard finishing process for critical hardened surfaces. Hard turning is best accomplished with cutting inserts made from either CBN (Cubic Boron Nitride), Cermets or Ceramic. Since hard turning is single point cutting, a significant benefit of this process is the capability to produce contours and to generate complex forms with the inherent motion capability of modern machine tools. High quality hard turning applications do require a properly configured machine tool and the appropriate tooling. For many applications, CBN tooling will be the most dominant choice. However, Ceramic and Cermets also have roles with this process. Tool wear describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tool, tool bits, or drill bits that are used with machine tools.

Types of wear include: Flank wear in which the portion of the tool in contact with the finished part erodes. Can be described using the Tool Life Expectancy equation. Crater wear in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.

A. Crater Wear
- Tool-chip interface

- Predominant at high speed
- Mitigated by efficient use of carbides

B. Flank wear
- Tool-work piece interface
- Predominant at low speeds

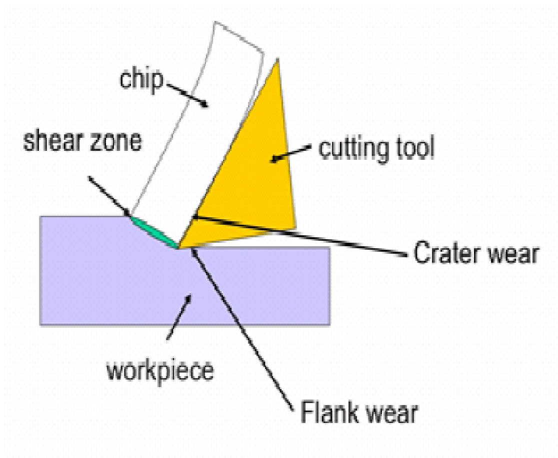

Fig. 1: Tool Wear

B.1 Effects of Tool Wear
Some General effects of tool wear include:
- Increased cutting forces....
- Increased cutting temperatures
- Poor surface finish
- Decreased accuracy of finished part
- May lead to tool breakage

B.2 Surface Roughness
The aggregate of the irregularities that form the micro relief of a part's surface. Surface roughness results mainly from plastic deformation of the surface layer of a work-piece during machining. It is caused by, for example, irregularities of a tool's cutting edges, friction, the tearing of particles of material from the surface of the work piece, and vibration of the work piece or the tool. Surface roughness is an important index in the specifications of a manufactured article. It affects the service properties of machine parts and assemblies, such as the wear resistance of rubbing surfaces, fatigue strength, corrosion resistance, and the maintenance of

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negative allowance in tight fits. Surface-roughness requirements are specified on the basis of the designated purpose of the surfaces of parts and the design characteristics of the parts. For a long time, a system characterizing the finish of a surface by means of classes of surface roughness was used in Soviet production. A new system, which was introduced on Jan. 1, 1975, replaced the classes of surface roughness that were previously used in the USSR. The extensive set of parameters of the new system facilitates the specification of precise requirements for surfaces intended for various purposes. When numerical values of surface roughness are determined, reference is made to a single datum line, for which the mean line m of a surface profile is used. Measurements are performed within the limits of a roughness-width cutoff l, that is, the length of the surface segment chosen for the measurement of roughness without taking into account other types of irregularities, such as waviness, whose spacing is greater than l. The numerical value of the roughness-width cutoff may be 0.01, 0.03, 0.08, 0.25, 0.8, 2.5, 8, or 25 mm. Quantitatively, surface roughness is evaluated by means of one or more of the following main parameters: the arithmetical average deviation of the surface profile (Ra), the height of irregularities at ten points (Rz), the maximum height of irregularities (Rmax), the average spacing of irregularities (Sm), the average peak spacing of irregularities (S), and the sampling length of the profile (tp).

B.3 Forces In Turning

Three forces acting on a cutting tool are shown in Fig. 1.12:

- Cutting force, Fc: acts downward on the tool tip. This is the force that supplies energy required for cutting operation.
- Thrust force, Ft: acts in longitudinal direction. This force is also called the feed force because it is in the feed direction.
- Radial force, Fr: acts in radial direction and tends to push the tool away from the work piece.

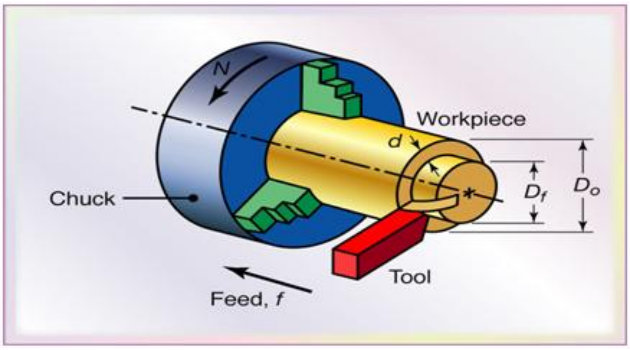

Fig. 2: Forces in Turning

II. LITERATURE SURVEY

Robert, et. al. had investigated Formation of the segments during the turning of hardened steel causes their elongation and decreasing the chip thickness. The result is formation of thin long chips, the chip ratio is smaller than 1, in comparison with the turning of annealed steel (thick and continuous chip, with the chip ratio higher than 1). The length of segments and the segmentation frequency increase with cutting speed. This process of the chip formation significantly affects all parameters related to the plastic deformation in the cutting zone. Moreover, the formation of the segmented chip causes instability of a cutting process, the high intensity of tool wear and generation of significant heat in the cutting zone. The chip thickness during turning of hardened steel 100Cr6 is much lower than for turning of annealed one. Formation of the segments during the turning of the hardened steel causes their elongation and decreasing of the chip thickness. [1]

HamdiAouici, et. al. had studied The effects of cutting speed, feed rate, work piece hardness and depth of cut on surface roughness and cutting force components in the hard turning with AISI H11 steel using cubic boron nitride (CBN 7020 from Sandvik Company) which is essentially made of 57% CBN and 35% TiCN.Four-factor (cutting speed, feed rate, hardness and depth of cut) and three-level fractional experiment designs completed with a statistical analysis of variance (ANOVA) were performed. Mathematical models for surface roughness and cutting force components were developed using the response surface methodology (RSM). This research seems that the best surface roughness was achieved at the lower feed rate and the highest cutting speed. The effects of two-factor interactions feed rate and depth of cut, cutting speed and work piece hardness, cutting speed and feed rate, work piece hardness and feed rate, and the products(H2 and ap2) appeared also to be important. The feed force (Fa) and the cutting force (Fv) are strongly influenced by the dept of cut, (56.77%) and (31.50%) respectively. On the opposite, the cutting speed has a very small influence (0.14%). [2]

EsmaeilSoltani, et. al. attempt has been made to model and optimize hard turning **AISI D3 hardened steel** using response surface methodology effects of four machining parameters, including cutting speed, feed rate, hardness and tool corner radius were investigated based on two performance characteristics involving surface roughness and main cutting force. He used **Central composite design (CCD)** as a experimental design and **Al2O3/TiC mixed ceramic tool** with three different corner radius including 0.4, 0.8 and 1.2 were employed to accomplish 30 tests with six center points. This investigation results that Sequential approximation optimization method was applied to obtain optimal condition of machining factor. In this way, 184.34m/min for cutting speed, 0.05mm/rev for feed rate, 49HRc for work piece hardness and 1.2mm for tool corner radius were proposed as optimal levels of machining parameters in order to minimize surface roughness and main cutting force. Under the optimal condition, surface roughness and main cutting force increased 15% and 21% respectively in comparison with initial condition. [3]

Suleiman Abdulkareem,et. al. done the experimental investigation of the influence of the three most important machining parameters of **depth of cut, feed rate and spindle speed** on surface roughness during turning of **mild**

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steel and used **Box Behnken experimental design method** as well as **analysis of variance (ANOVA)** to analyze the influence of machining parameters on surface roughness height Ra using **multiple linear regressions**.Confirmation results were used to confirm that mathematical models are good enough to effectively represent machining criteria of surface roughness Ra during the study. He conclude on the basis of experiment that he feed rate is found to be the most important parameter effecting ra, followed by cutting speed while spindle speed has the least effect and machining with high cutting speed and spindle speed has positive effect on Ra as againstfeed rate. The predicted value of Ra matches the experimental values reasonably well, with high value of coefficient of determination ($R2 = 0.99$) for Ra. The variation in percentage error for R is between 1 to5%, which shows that the model developed for Ra is accurate, and can be used for predicting the surface roughness. [4]

Sudhansu Ranjan Das,et. al. investigated the effect of machining parameters such as cutting speed, feed and depth of cut on surface roughness during dry turning of hardened **aisi 4340 steel** using coated carbide inserts. Turning of hardened steels using a single point cutting tool has replaced the cylindrical grinding now as it offers attractive benefits in terms of lower equipment costs, shorter set up time, fewer process setups, higher material removal rate, better surface quality and elimination of cutting fluids compared to cylindrical grinding.A **full factorial design of experiment** is selected for experimental planning and the **analysis of variance (ANOVA)** has been employed to analyze the significant machining parameters on surface roughness during turning.In the result they observed from the ANOVA that feed (60.85%) is the most significant parameter followed by cutting speed (24.6%) and the two level interactions were significant between cutting speed, feed (6.23%) and depth of cut-feed (2.62%) on surface roughness. From the experimentation it is found that, depth of cut did not impact the surface roughness in the studied range, significantly. The most optimal results for surface roughness were observed when cutting speed was set at 150 m/min and feed of 0.05 mm/rev. The present research work on turning of hardened AISI 4340 steel with CVD multilayer coated carbide insert will be useful for the advanced engineering industries those are working in the field of precision machining. [5]

III. RESEARCH OBJETIVES

- To evaluate optimum cutting condition base on surface roughness.
- Analysis of chip morphology during hard turning.
- Evaluate the tool flank wear and rise of temperature on the base of chip morphology.
- After perform statistical analysis like TAGUCHI, ANOVA and REGRATION they will provide the relationship between input and output variables.
- To validate the predictive equation developed by regression analysis as the function of cutting length, tool wear, surface roughness and temperature which will be helpful to industries.

IV. EXPERIMENTAL SETUP

Experimental unit: Here in my experiment unit is lathe machine turning round bar.
Factors: Because of the turning process; I varied cutting conditions like speed, feed and depth of cut were three factors.
Level: The possible values of factor.
Factors with level value:

Table. 1: Factors and their levels

Factors	**Level 1**	**Level 2**	**Level 3**
Speed (m/min)	29.83	59.66	84.72
Feed (mm/rev)	0.06	0.06	0.06
Depth of cut (mm)	0.5	0.4	0.3

By using minitab-16 software insert the 3 factors and 3 levels in taguchi design of experiment method I got the following array and design of steps to perform experiment.

- Taguchi Orthogonal Array Design L9(3**3)
- Factors: 3
- Runs: 9
- Columns of L9(3**4) Array 1 2 3

Orthogonal array L9 of Taguchi:

Table. 2: Orthogonal array L9 of Taguchi method using minitab-16 software

Test No.	Speed	Feed	Depth of cut
1	29.83	0.06	0.5
2	29.83	0.06	0.4
3	29.83	0.06	0.3
4	59.66	0.06	0.4
5	59.66	0.06	0.3
6	59.66	0.06	0.5
7	84.72	0.06	0.3
8	84.72	0.06	0.5
9	84.72	0.06	0.4

Experiments were planned according to Taguchi's L9 orthogonal array, which has 9 rows corresponding to the number of testes (9 degree of freedom) with 3 columns at three levels as shown in table 2. The first column of table 2 was assigned to depth of cut, the second to the feed rate and the third column was assigned to the cutting speed. It means a total 9 experimental number must be conducted using the combination of levels for each independent factor (speed, feed and depth of cut) as shown in table 2. This orthogonal array is chosen due to its capability to check the interactions among factors. The experimental results are then transferred in to a Signal to Noise (S/N) ratio. There are three categories of quality characteristic in the analysis of the S/N ratio, (i) the-lower-the-better, (ii) the-higher-the-better and (iii) the-nominal-the better. Regardless of the category of the quality characteristic, process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The category the-lower-the-better was used to

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calculate the S/N ratio for both quality characteristics surface roughness and work piece surface temperature, according to the equation:

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where:
η = Signal to noise ratio
n = Number of repetitions of experiment
y_i = Measured value of quality characteristic

- In this experiment I have used the lower the better category of quality characteristic in the analysis of signal to noise ratio.

Table. 3: Different formula for finding S/n ratio

Choose...	S/N ratio formulas	Use when the goal is to...	And your data are...
Larger is better	S/N = -10 Log10 [mean of sum squares of reciprocal of measured data]	Maximize the response	Positive
Nominal is best	S/N = 10 Log10 [square of mean/ variance]	Target the response and you want to base the S/N ratio on standard deviations only	Positive, zero, or negative
Smaller is better	S/N = -10 Log10 [mean of sum of squares of measured data]	Minimize the response	Non-negative with a target value of zero

Cutting Conditions:
Cutting tests were carried out on lathe machine under dry conditions. The lathe machine, located in the LDRP WORK-SHOP, was of type Simple turn HMT and is shown in Figure 3.1.

Fig. 3: Lathe machine

The specifications of lathe machine were as per the table 4:

Table. 4: Specification of lathe machine

Sr. No.	Descriptions	Specifications
1	Name of machine	Center lathe
2	Make	HMT
3	Distance between centres	1000 mm
4	Length of bed	1000mm
5	Height of center	200 mm
6	Spindle speed range	63-1400 rpm
7	Spindle	8 spindle speed
8	Type of drive	All gear drive
9	Motor	3 h.p

Cutting Inserts:
CBN tools may be used either in the form of small solid tips or or as a 0.5 to 1 mm thick layer of of polycrystalline boron nitride sintered onto a carbide substrate under pressure. In the latter case the carbide provides shock resistance and the CBN layer provides very high wear resistance and cutting edge strength. Cubic boron nitride is the standard choice for machining alloy and tool steels with a hardness of 50 RC or higher. Typical cutting speeds: 30 - 310 m/min.

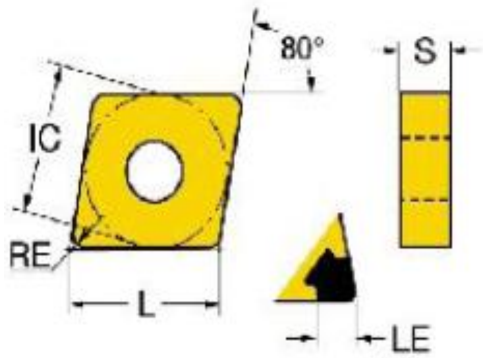

Fig. 4: Cutting tool inserts used in experiment

The cutting tool and tool holder assembly are shown in Figure 3.3.

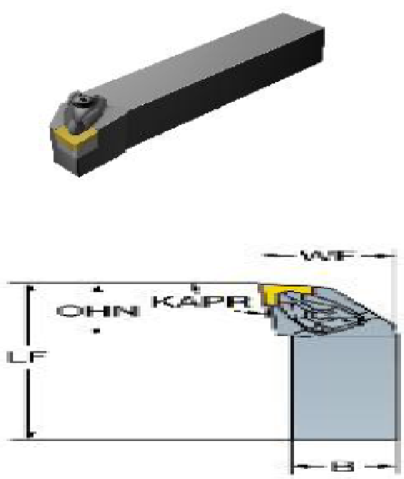

Fig. 5: The cutting tool and tool holder assembly

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Work-piece Material:

AISI 4340 ALLOY STEEL 38 mm diameter

Category	**Steel**
Class	**Alloy steel**
Type	**Standard**
Common names	**Nickel-chromium-molybdenum steel**
Designations	**Germany:Din 1.6565 Japan:Jis Sncm8 United Kingdom: B.S. 2 S 119 , B.S. 3 S 95 , B.S. 3111 Type 6 , B.S. 817 40 United States: AMS 5331 , AMS 6359 , AMS 6359B , AMS 6414 , AMS 6414A , AMS 6415 , AMS 6415G , ASTM A322 , ASTM A331 , ASTM A505 , ASTM A519 , ASTM A547 , ASTM A646 , MIL SPEC MIL-S-16974 , SAE J404 , SAE J412 , SAE J770 , UNS G43400**

V. RESULTS AND DISCUSSION

The measured values of surface roughness of work piece by using CBN insert according to taguchi orthogonal array from table 4.2 to all experimental runs are given in table 5.

Table. 5: Experimental results for surface roughness

Sr. No.	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (mm/rev)	Surface roughness (µm)
1	31	0.5	0.06	0.725
2	43	0.5	0.06	0.680
3	63	0.5	0.06	0.580
4	31	0.4	0.06	0.744
5	43	0.4	0.06	0.675
6	63	0.4	0.06	0.560
7	31	0.3	0.06	0.800
8	43	0.3	0.06	0.670
9	63	0.3	0.06	0.610

A. *Signal to Noise ratio:*

Analysis of the influence of each control factor (S, F and D) on the surface roughness has been performed with a so-called signal to noise ratio response table. Response table of S/N ratio for surface roughness are shown in table. It shows the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to other. We are using the S/N ratio as smaller to better because of minimize the response and data is non-negative.

Table. 6: S-N ratio

Cutting Speed (m/min)	Depth of Cut (mm)	SR (µm)	SNR
31	0.5	0.725	2.793
43	0.5	0.680	3.350
63	0.5	0.580	4.731
31	0.4	0.744	2.569
43	0.4	0.675	3.414
63	0.4	0.560	5.036
31	0.3	0.800	1.938
43	0.3	0.670	3.479
63	0.3	0.610	4.293

Table. 7: Response Table for Signal to Noise Ratios (Smaller is better)

Level	Speed	DOC
1	2.433	3.237
2	3.414	3.673
3	4.687	3.625
Delta	2.254	0.436
Rank	1	2

Note: Factor FEED is (essentially) constant. No calculations were done.

The influence of control factor can be more clearly presented with response graph as shown in figure 6.

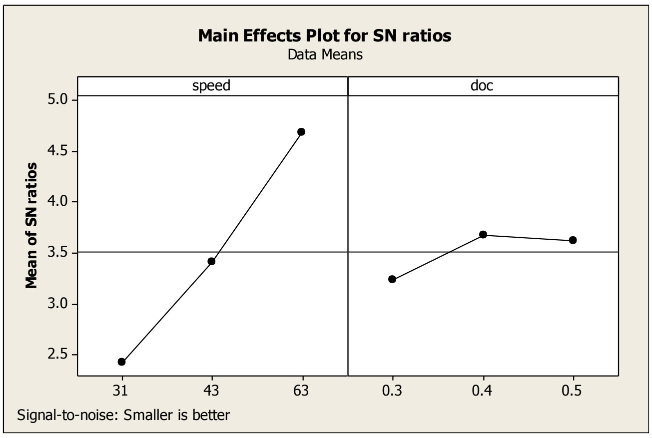

Fig. 6: Main effect plots for S/N ratio for surface roughness

Surface roughness appears to be an almost linear increasing function of feed rate and decreasing function of cutting speed. Thus in order to reduce the level of surface roughness, feed rate (F) should be set to its Constant level (0.06 mm/rev) and speed (S) to its highest level (63 m/min). Also, high level (0.5mm) or low level (0.3mm) of depth of cut, may be preferred, while the effect of D has not been found statistically significant. Experimental readings of surface roughness of turned round bar are shown in table at every three cut or a every 90 mm cutting length by using surface

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roughness tester SJ-201

Table. 8: Surface roughness of CBN cutting tool insert

Sr. No	Cutting length (mm)	Surface roughness (µm)
1	90	0.585
2	180	0.590
3	270	0.602
4	360	0.610
5	450	0.615
6	540	0.618
7	630	0.625
8	720	0.653
9	810	0.655

Now plot the graph of above readings of surface roughness by using origin 6.1 software. Figure 6 6 that the surface roughness increased steadily until around cutting length 630 mm. After that the surface roughness oscillated while increasing at a lower rate.

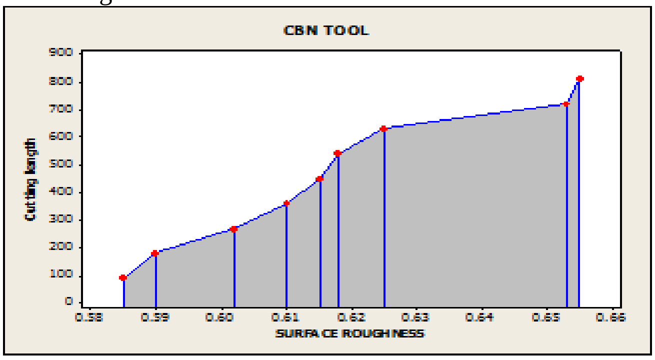

Fig. 7: Surface roughness v/s Cutting length of CBN cutting tool insert

Table shows the output for the regression of surface roughness on the cutting length using Minitab 16 software. A null hypothesis (Ho) that the cutting length has no effect on the surface roughness and an alternative hypothesis (Ha) that the cutting length has an effect on surface roughness were used. Again using α-value of 0.05, the null hypothesis is rejected in favor of the alternative hypothesis since the P value for this regression is 0.000. And so it can be concluded that the cutting length has a significant effect on surface roughness.

Table 9: Regression of surface roughness on the cutting length for CBN tool

Weighted analysis using weights in Surface roughness in µm. The regression equation is

sr new = 0.978 - 0.00532 speed - 0.158 doc

Predictor	Coef	SE Coef	T	P
Constant	0.9779	0.048	20.32	0.000
speed	-0.00532	0.0006	-8.87	0.000
doc	-0.15833	0.097	-1.63	0.154

S = 0.0237482 R-Sq = 93.1% R-Sq(adj) = 90.8%

VI. CONCLUSION

In this study following conclusions are drawn:

- During hard turning of AISI-4340 steel using CBN tool, optimum cutting conditions for minimizing surface roughness are63 m/min cutting speed, 0.06 mm/rev feed rate and 0.4 mm depth of cut.
- Practical performance has been done for tool wear and surface roughness values based on cutting length.
- Prediction equation has been developed by regression analysis and that prediction value is compared with experimental results for validation. Percentage variation found within 10**%** for flank wear and % for surface roughness which is acceptable according to literature review.
- This equation can be helpful for designing a tool in industries.
- On basis of chip formation during hard turning at optimum condition, surface roughness value is decreasing when shape of chip changes from segmented type to small radii C-type.
- As same as when flank wear increases, shape of chip changes from continuous wavy type to spring saw tooth type(at the starting stage) **-**saw tooth type to tubular helix type(at the middle stage) **-**larger radial spring type to continuous Saw tooth type (at the last stage).

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