A STUDY OF INCREASE TOOL LIFE OF MILLING MACHINE USING DYNAMIC MILLING

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ABSTRACT

Milling is a commonly used machining process where a rotating cutter removes material from the workpiece. In recent years, attention has been turned towards so called dynamic milling methods which differ from the conventional way of milling. Dynamic milling normally uses, as opposed to the conventional way, more of the axial cutting edge, smaller radial depth of cut, significantly higher cutting speed and feed per tooth. The method has demonstrated potential to save both time and money under specific circumstances, for manufacturing companies. The results of this study show that dynamic milling parameters can give several benefits regarding tool life and material removal rate and minimize machining cost. When machining in Hardox 600 end mills able to achieve a higher material removal rate and cutting tool lifetime with dynamic parameters compared to more conventional ones Results from the analysis showed that the dynamic parameters generated a smoother surface while the surface results from Hardox were more equivocal. Dynamic milling is a method that often uses the full length of the tool combined with a small radial depth, higher cutting speed and feed per tooth. This can potentially increase the material removal rate significantly compared to traditional methods. Dynamic milling techniques also use a toolpath programmed to achieve the most efficient cut. This is often done by keeping the tools angle of engagement constant through the operation in order to keep a consistent load. The main conclusion was that milling with dynamic parameters is generally more advantageous and should be utilised, if possible.

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1. Objective

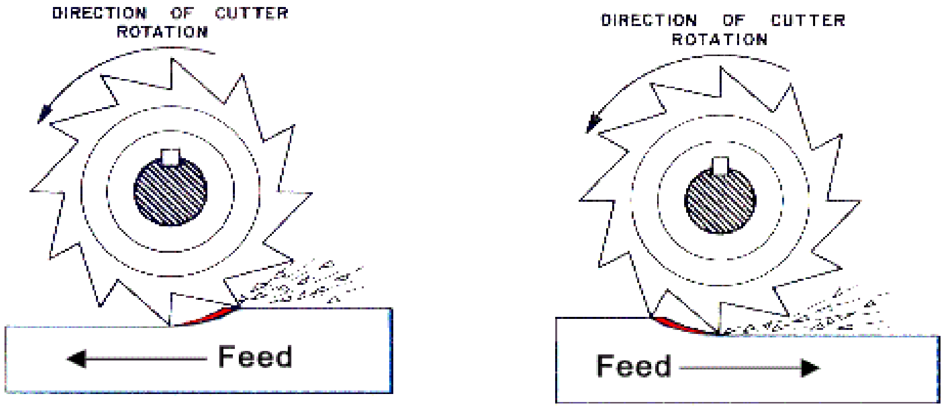
The aim of this paper is to gain a better understanding of how the tools wear in conventional- and dynamic milling depends on working materials, cutting tool properties and various cutting parameters. Specifically how the material removal rate Q (cm3/min) and the integral of Q (i.e the total volume) varies with different cutting parameters. This will make it possible to determine if there are benefits with dynamic milling in terms of the tools life and productivity compared to conventional milling. The tools being studied are selected from ISCAR's MULTI-MASTER end mills and the working materials hardened steels Hardox 600.

1.1 Milling

1.1.1 Up- and down milling

The cutting process in milling is inherently intermittent, which means that each tooth of the tool is only cutting up to half of a revolution of the cutter. Hence, the cutting edges on the tool are making periodic impacts with the work-piece, as opposed to continuous machining operations e.g. drilling and turning. There are two different types of milling: up- and down-(climb) milling. The principles of these are shown in Figure 1.

In up-milling the work-piece is fed opposite to the tools rotation, resulting in a chip thickness of zero in the beginning of the cutting process which then increases in thickness towards the end of the procedure. The high cutting forces in up-milling tend to press the milling tool and the work-piece away from each other which may tend to lift the workpiece from the machine table. It is thus important to fasten the work-piece carefully. In down-milling, the work-piece is fed in the same direction as the tool's rotation giving a large chip thickness at the beginning of the cutting process which eventually becomes zero at the end of the procedure. Because of this, the pressing effect that occurs in up-milling is not obtained in down-milling. The cutting forces in down-milling instead strive to pull the work-piece towards the cutter which keeps the insert held in engagement.



Up-milling **Down-milling**

Fig -1

1.2 Dynamic milling

When a cutter passes a corner the traditional way the tool engagement will increase thus increasing the load on the cutter (Figure 2). As the tool engagement increases the time each cutting edge (flute) is in contact with air decreases, consequently the chance the tool has to release heat is reduced.

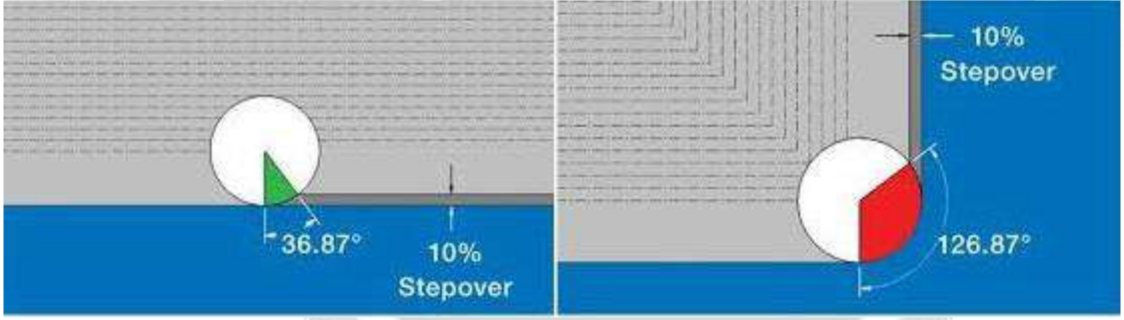


Fig -2

Dynamic milling is a broad concept for milling methods that combine a large axial cutting depth, small radial depth and an optimized tool path (Figure 2). The different CAM manufacturers have their different brand names for this technique such as e.g. Dynamic Mill, VoluMill and TRUEMill. Depending on the manufacturer, the methods can work in different ways. Some methods aim to create a toolpath that completely avoids cornering in order to keep a constant engagement of the cutter, thus a constant load. However, other methods do not always strive to control the angle of engagement but instead dynamically adjusts e.g. feed rate and other parameters in order to not exceed a specific material removal rate.

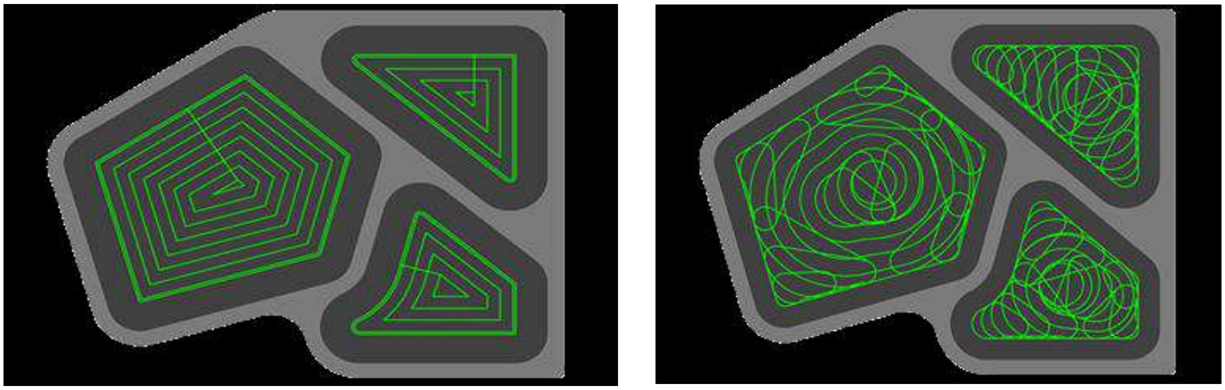


Fig -3

Typical toolpaths in conventional- (left) and dynamic-milling (right) The low radial depth and optimized toolpaths makes it possible to machine at higher speeds and feed rates than recommended by tool manufacturers. Under certain circumstances, dynamic milling methods have been able to increase material removal rate drastically as well as reducing tool wear.

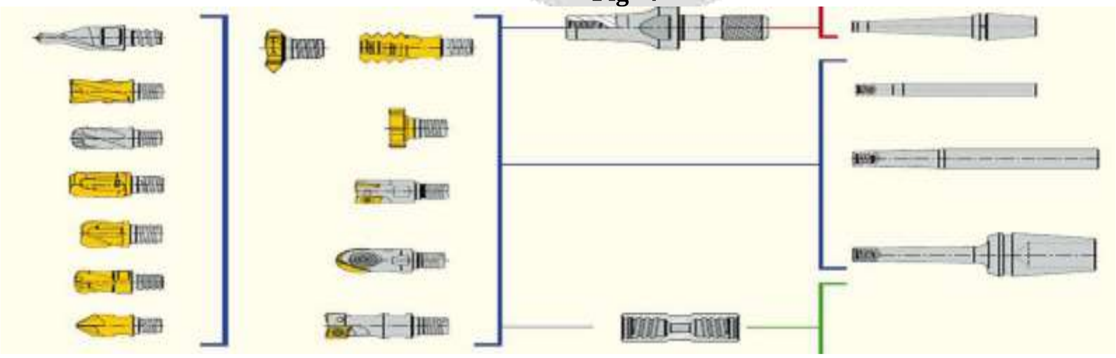
2. Cutting data

The different parameters that control the milling process are called cutting data. There are several definitions that needs to be explained for a deeper understanding of how the processing is done and which parameters that affects the outcome.

2.1 MULTI-MASTER

The MULTI-MASTER (MM) concept was introduced by ISCAR in the year 2000. The concept is a system of rotating tools with interchangeable heads and shanks. A chosen MM shank connects with a solid carbide head by specially designed threads which enable repeatable, easy and fast replacements of the milling heads with no setup time between them. The same shank can support heads of different geometries and grades just like a specific head can be inserted into shanks of different materials (steel, tungsten carbide or tungsten). A relatively small number of different shanks and heads thus give numerous combinations of cutting tools which gives great versatility and reduces the need for specially designed tools. The concept also offers adapters which gives the opportunity to machine with large overhang without having to purchase a specific long reach tool. Some of the different heads, adaptors and shanks can be seen in Figure 4.The MM concept started out with a selection of indexable solid carbide tools but quickly it was realized that there were significant advantages also for tools with indexable inserts. It developed into the SHANKMASTER (TS) system consisting of solid carbide shanks and milling heads with indexable inserts. It uses the same MM thread to connect the two, the difference is that the TS shanks uses an external thread and the heads with indexable inserts, an internal. This is the opposite thread system that MM utilizes. However, with the use of an adaptor the TS shanks can be used with MM milling heads as well. Nowadays ISCAR's different systems such as e.g. SUMOMILL, HELIDO UPFEED and TANGPLUNGE are all usable with MULTI-MASTER and SHANKMASTER creating a variety of combinations for different situations.

Fig -4



3. Tool wear

3.1 Flank wear

The flank wear results most commonly from abrasion on the cutting edge of the tool. The wear occurs on the relief face and creates a wear land (Figure 6). The resulting wear land rubs and damages the machined surface and produces large flank forces which increase deflections and reduce dimensional accuracy. The maximum land width is used as an indication of the extent of the flank wear. The severity of the flank wear increases until a critical point is reached (Figure 5). Abrasion- and deformation-resistance of the tool material can be increased in order to minimize the flank wear. The usage of hard coatings on the tool could also be applied to resist the flank wear.

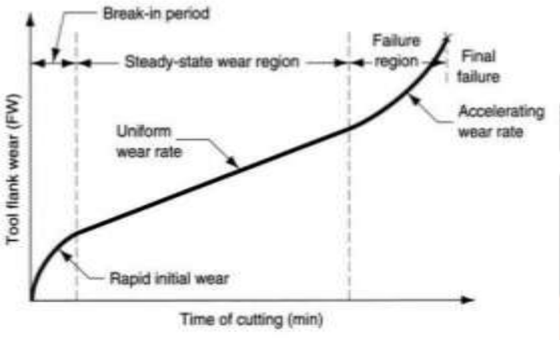


Fig -5

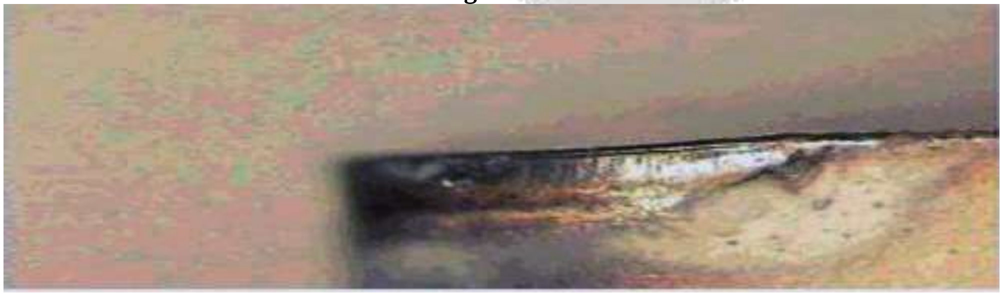
(Measure of tool wear. Crater wear follows a similar growth)

Fig -6

3.2 Plastic deformation

Plastic deformation of the cutting edge can occur in the form of an indentation if the temperature and load becomes too high for the tool to support (Figure 7). It usually appears at high cutting speeds and feeding rates, leading to softening of the tool material and high stress. Using a tool with a deformed edge of this type can lead to insufficient surface finish, chip control and eventually tool breakage.

Fig -7



3.3 Notch wear

At the point of contact between the tool and the unmachined surface or free edge chip of the tool, notch wear can be developed

Fig -8

4. Tool life

When the tool gets worn out to a point where it no longer can perform satisfactory, the tool needs to be replaced. The factors deciding if the tools performance is sufficient can be the resulting surface finish, dimension tolerances, chip controlling or if the wear is so large that the cutting edges risk fracturing. If the tool is machined past this point, it can lead to tool breakage. It is therefore very important to be able to predict the tools theoretical life span.35 Because the tool life depends on many different factors like cutting conditions and tool material it is difficult to produce methods that accurately predict tool life. The most commonly used method is the Taylor tool life equation.

$$vc \cdot T^n = C$$

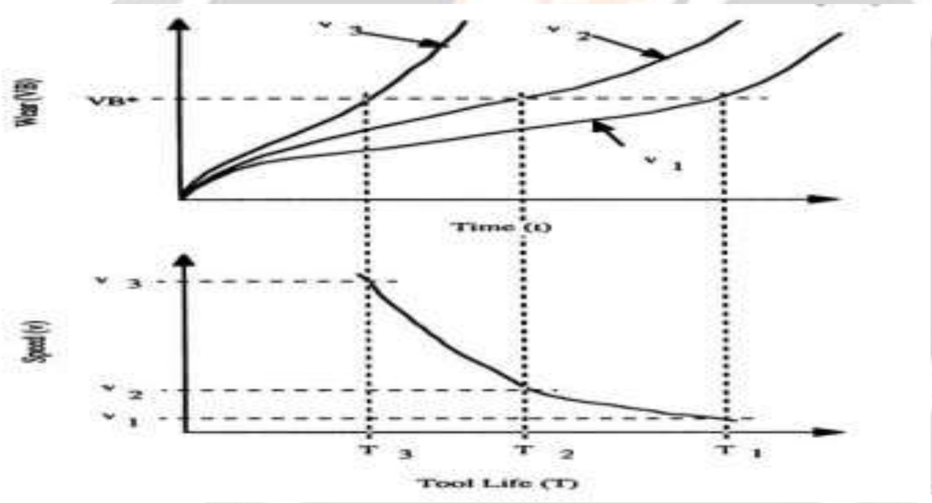


Fig -9

5. Experiments

The following segment describes what machines and tools were used in the experiments and how they were performed.

5.1 Experimental setup

5.1.1 Milling machine

The machine used in the experiments is shown in Figure 8. Its specifications are listed in table 1

Fig -10

TABLE LENGTH	900 mm
TABLE WIDTH	600 mm
LONGITUDINAL TRAVEL(X-AXIS)	800 mm
VERTICAL TRAVEL(Y-AXIS)	500 mm
CROSS TRAVEL(Z-AXIS)	550 mm
TABLE LOAD MAX.	450 kg
TAPER IN SPINDLE	40 ISO
SPINDLE SPEEDS	20-5000rpm
FEED	1-4000m
TOOL MAGAZINE	20

Table 1

5.1.2 Shank

The MULTI-MASTER integral shank (Figure 9) is used due to its low overhang and high stability. Specifications for the shank are listed in Table 2.

PART	SS	TSI	D2(mm)	L(mm)	L1(mm)	L3(mm)	R(mm)
MM S2	40	T08	11.60	45	26	20	6

Table 2

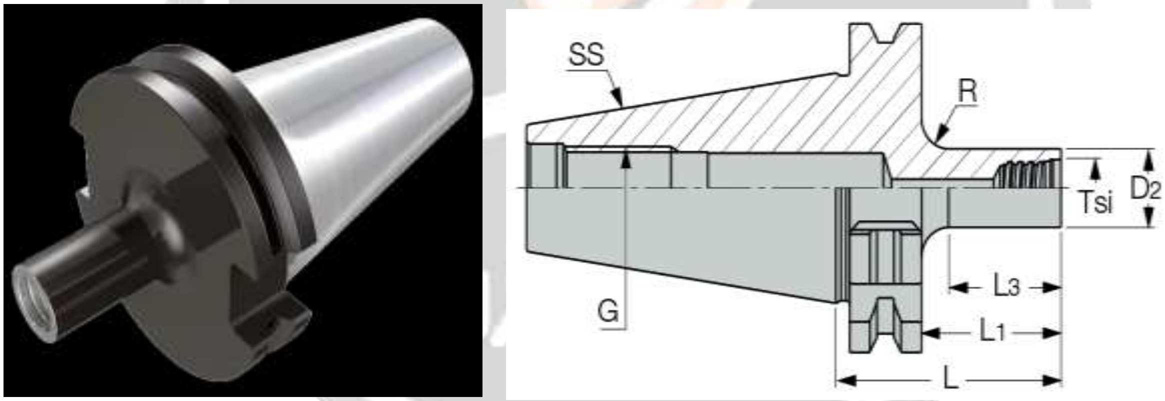


Fig -11

5.1.3 Cutting tool

MM A

The MM A tool seen in Figure 10 uses ISCAR's grade ICX. This gives the tool high toughness and resistance to wear. It's useful in demanding situations especially when machining hardened steels up to 62 HRC, titanium and stainless steel.

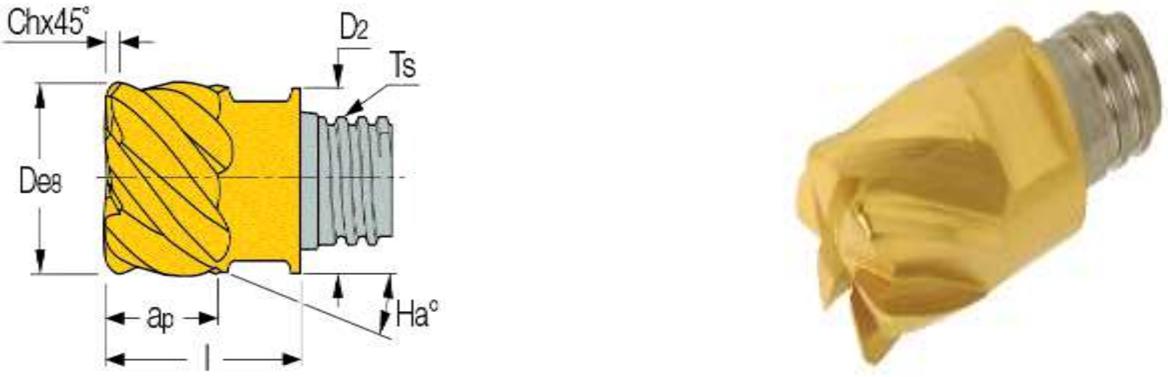


Fig -12

5.2. Experimental data

Table 3 shows the cutting data for all the tests that were performed.

TEST	TOOL	MATERIAL	Ae(mm)	Ap(mm)	Vc(mm/min)	Fz(mm/tooth)
1	MM A ICX	HARDOX 600	0.5	9.0	130	0.09
2	MM B ICY	HARDOX 600	0.5	9.0	130	0.09
3	MM A ICX	HARDOX 600	0.7	9.0	160	0.09
4	MM A ICX	HARDOX 600	0.5	3.0	60	0.05
5	MM B ICY	HARDOX 600	0.5	2.0	40	0.05
6	MM A ICX	HARDOX 600	0.7	9.0	160	0.14
7	MM B ICY	HARDOX 600	0.7	9.0	160	0.09

Table 3

6. Results and analysis

6.1. Tool life

The results from the experiments are shown in Table 4 where the material removal rate Q, number of passes, total material removed and lifetime are displayed for each tool. In the appendix, all the results from the USB microscope are presented, except for the tests that led to tool breakage right away. Some of the tests had considerably longer tool life than expected and are therefore not tested to full tool life, due to time-, material land cost-constraints. These have a "+" symbol in the Tool life column to demonstrate that they have longer actual tool life. Due to an unknown restriction of the table feed, test 6 did not perform as intended. The result from test 6 is therefore ignored The material removal rate Q is calculated with equation , the number of passes is the number of times the tool machined the 300 mm long edge of the material and material removed is calculated by multiplying Q with the tool life (the total time of engagement).

6.2. Hardox 600

Results from the tests in Hardox 600

Table 4

TEST	TOOL	PASSES	MATERIAL REMOVED(cm3)	TOOL LIFE(min.)
1	MM A ICX	260	352	42+
2	MM B ICY	356	478	57+
3	MM A ICX	397	751	52+
4	MM A ICX	1	4.5	0.6
5	MM B ICY	123	369	116
6	MM A ICX	1	-	-
7	MM B ICY	59	116	8+

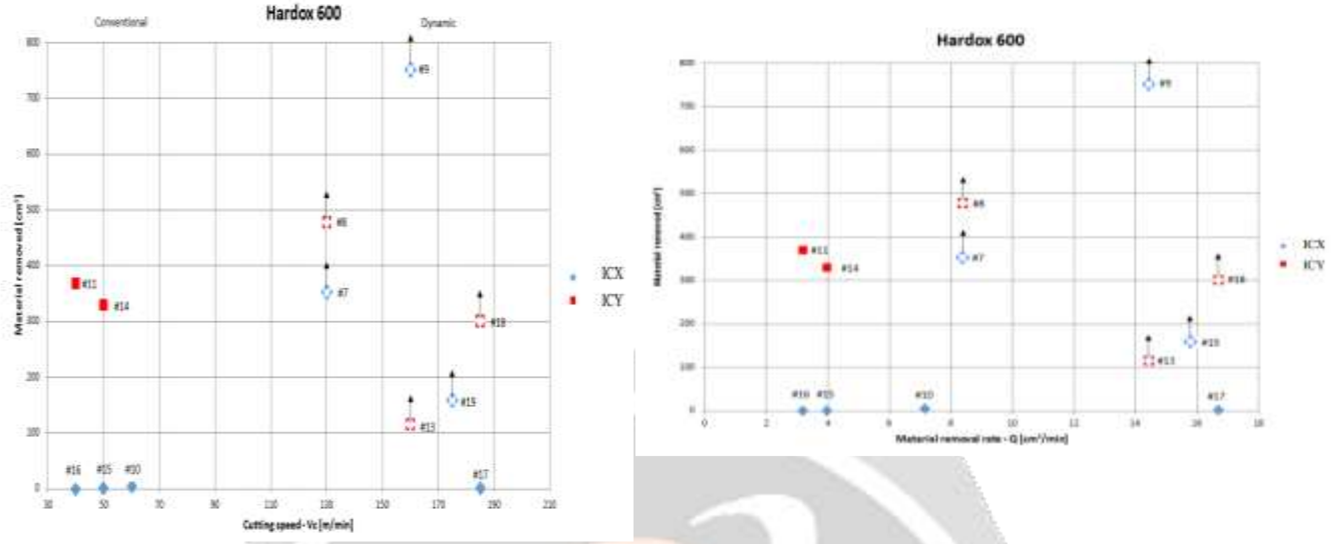


Fig -13

Cutting speed versus material removed in Hardox 600, and Material removal rate versus material removed in Hardox 600

6.3 Discussion

The results clearly show major differences between milling with conventional and dynamic cutting parameters. Especially in Hardox 600 where the tools machined with dynamic parameters were able to achieve both higher material removal rate and lifetime.

7. Conclusion

The study shows that dynamic milling methods can give several benefits regarding material removal rate,material removed, the tools wear and lifetime. By achieving a higher material removal rate, the tools productivity increases dramatically. In addition, the surface also achieves a finer smoothness than the conventional parameters.

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