

PREPARATION STEPS OF A CONNECTING ROD'S 3D GEOMETRY TO BE MANUFACTURED ON A NC CENTER

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ABSTRACT: This case study presents a sequence of operations performed in a 3D environment, in order to obtain a full physical replica of a previously optimized 3D geometry of a connecting rod by means of NC driven manufacturing process. The method highlights some of the technical impediments that can be found along the process, as it is custom fitted to a certain part model. It produced valid NC codes written in the G code. The post-processor involves the NC center that was used for the actual manufacturing including its tools setup. The connecting rod's 3D geometry was divided in two sections and considered individually as its head and body. Only important operations are presented in the study and the overall results that they produced. It also presents some operations regarding generation and export techniques that were used to obtain G code files fed afterwards to the NC center. The procedure aims to be a valid alternative to the classical forging process of connecting rods.

KEY WORDS: 3D setup, connecting rod, NC manufacturing.

1 INTRODUCTION

The NC machining of single parts or components is an up to date technology, widely used throughout the entire mechanical related industries. It allows users or companies to obtain finite results, based on their own concepts and designs or on imported ones. Thus, 3D environments that assist the engineers have developed special custom fitted modules to smooth the transition from a virtual geometry to a physical replica of it. In the present study, the authors are using *Catia* in order to generate the sequence of operations needed for the NC center, to properly manufacture a connecting rod. This procedure is only a final step in a much wider research that involved scanning the connecting rod, then retouching and finishing it in order to be imported as a 3D geometry. It then has undergone a series of tests that provided the authors with an optimization procedure and the corresponding geometry (Qiang et al., 2012). This one has to be machined on a NC center, namely the *Mazak Nexus 510C*. Several modules inside *Catia* were used for proper manipulation and set up before any NC code was generated.

The study shows print screens of simulated operations performed on the geometry, as well as a picture of the physical replica obtained at the end of the process by means of NC machining (Sanjeev et al., 2009).

Some operations as well as technical details were not mentioned, due to intellectual rights infringement because parts of the study involved an industrial private partnership. This led to expected results in terms of physical replica machined on a NC center. By means of both technical background and accumulated experience provided through partnership, we were able to overcome the difficulties that arose during the transition between CAD environment and the NC center, especially in terms of choosing the right postprocessor used by the machine (Mihalache et al., 2013).

From the originality point of view, we would have to mention that this procedure addresses some technical issues that are not properly explained by any manufacturer and are part of training capabilities to which not everyone has access. The connecting rod geometry was considered intricate enough because it contains lots of free form surfaces, angles, transition zones, inner channels or fillets that without a powerful 3D tool as *Catia* or something similar would be very hard if not impossible to machine by means of NC manufacturing, which may prove someday to be a viable alternative to the classical forging process (Hongbo et al., 2008).

The operations sequence involved constant changes of tools as well as many sets of passes and withdrawals guides in such way that the whole

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machining process would be continuous and uninterrupted (Ripanu et al., 2010).

The NC center has machined the connecting rod body in eight hours and its head in five hours, based on the codes fed to it.

2 METHOD DESCRIPTION

As it is the case with most software tools that interpret and generate codes, especially G-codes, the workflow has to take into account some guidelines that would ease up the process. Thus, three steps have to be considered: *the setup, the program* and *the output*. The setup involves analyzing the part to be machined, choose the actual setup, define the geometry, define the collision zones and create the tools. Programming defines the operations that will actually machine the desired part.

The output refers to the installation of the post processor which has to match the actual NC center. Post processing converts the generic internal tool path data into a format which is compatible with a specific machine tool controller combination. In order to post process, the user will need a tool path and the post processor itself.

2.1 Step 1. The setup

Looking at the connecting rod, it became visible that its two components should be treated separately. The two components are already digitized in form of *Catia* related files. By default, the head and the body of the connecting rod have their own global system of coordinates, this being one of the steps much needed in the process: the alignment of parts to a unique coordinate system. The next step consisted in the definition of the blank as well as the part's geometry. We have already registered the desired connecting rod material, namely *fortal*, in the software's library.

We now had to set a so called container or a collision free zone. Collision zones allow the cutter to avoid objects by using an axial containment plane

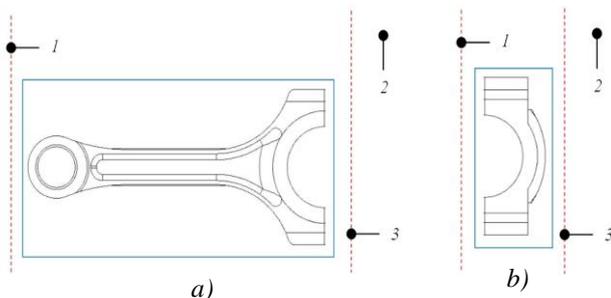


Figure 1. Collision zones setup.
 a) The body of the connecting rod;
 b) The head of the connecting rod

(1), start and return points (2), and also a clearance plane (3) (Fig. 1).

Another important step is to set up an avoidance perimeter in such a way to avoid a chuck. It is the containment plane mentioned above that will prevent tools from colliding with the NC station's components.

Operations such as roughing and finishing will need to use this containment group. The last step of the setup consists in setting up the tools that will be used in the manufacturing process. In both cases concerning the connecting rod head and body we have defined different tools such as: face mills (*customized to meet the requirements of a cylindrical frontal type of mill*) with different diameters, cylindrical frontal mills with inclined tips, ball tip mills with different diameters. Fillet mills were substituted by the ball tip mills.

2.2 Step 2. The program

In order to completely machine the connecting rod head, we had to set up seven different operations involving seven tool changes (Fig. 2). Some of the operations needed for the process of machining the desired part are: *roughing, profile contouring, sweeping* and *Z leveling*.

Having defined a rough stock (*the blank from which the cutter will machine the desired part*) (Fig. 3). We have to "tell" the software where a safety plan (*the above mentioned containment plane*) begins and also where the separation plane (*the above mentioned clearance plane*) does too (Fig. 4).

This will be set apart from the outer upper

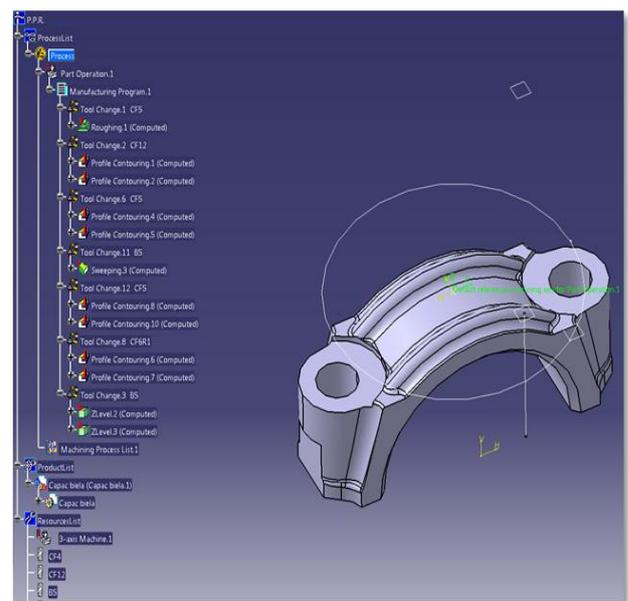


Figure 2. List of processes and tools used for virtual machining the connecting rod's head diameter of the part's ribs. This makes the software

to automatically show the cutter's position and alignment in with respect to the two defined planes, as well as all the intermediate planes that the tool

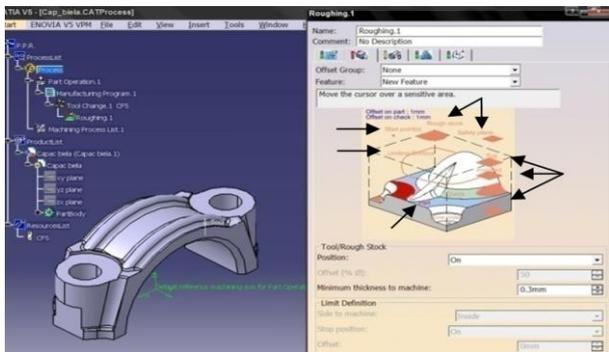


Figure 3. Defining the rough stock for the connecting rod's head

has to keep count of in order to fully machine the imposed geometry (Fig. 5).

The tool that performs the roughing operation is a cylindrical frontal type mill with a diameter of 5 mm (CF5).

Another operation required in order to properly machine the connecting rod head is the *profile contouring*. It has been carried out in different steps with various tools, such as cylindrical frontal mills with diameters of 12 and 5 mm (CF12 and CF5) and also a cylindrical frontal mill with a diameter of 6 mm and its tip inclined by a radius of 1 mm (CF6R1). The profile contouring involved the ribs that are present in the upper section of the part and also the transition areas towards the base of the part. Such areas are free forms surfaces that are very intricate from the geometrical point of view, which contain many slopes at different angles that are impossible to measure by traditional means. For now, they will be machined at a given angle and

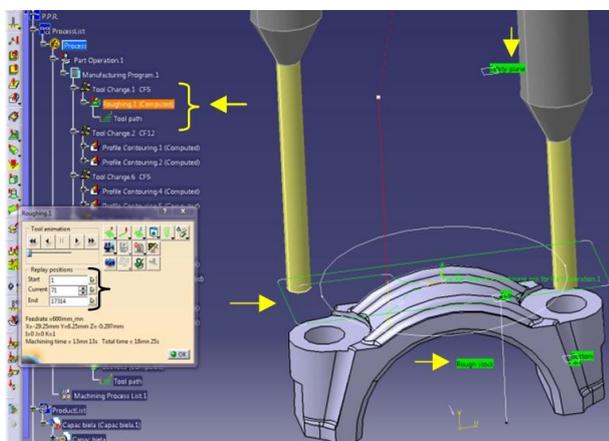


Figure 4. Defining the safety plane for the roughing operation

afterwards they will need additional operations such as Z leveling, in order to be fully machined. The

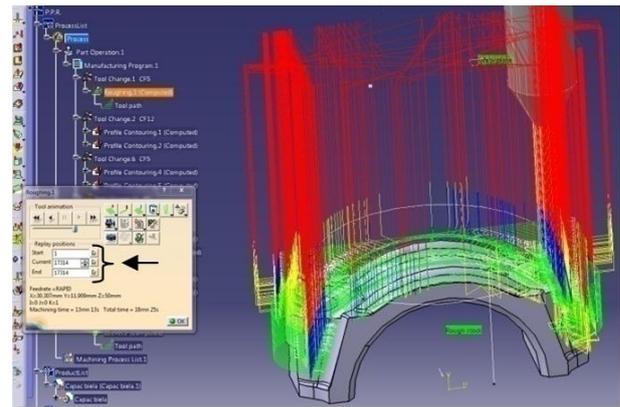


Figure 5. Roughing the connecting rod's head

holes for the bolts were profile contoured with the frontal cylindrical mill with its tip inclined after sweeping has taken place.

Another operation is being represented by *sweeping*. It has been carried out with a ball tip mill with a diameter of 5 mm (B5). The operation is similar to finishing; thus after its completion we would have a mirror like finish. It has been applied to the entire upper area of the connecting rod head,

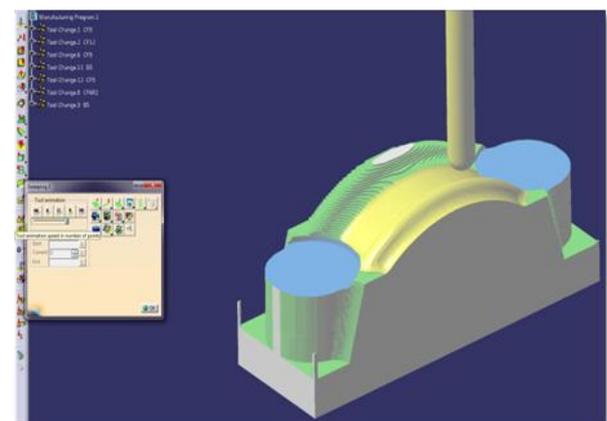


Figure 6. Sweeping the upper area of the connecting rod's head

as it may be seen from figure 6.

The last one of the operations needed in order to fully machine the connecting rod head is represented by so called *Z leveling*. It is an operation carried out along the Z axis, which is also the tool axis. Looking at figure 6, we can see that after a profile contouring, we have an angled surface that wraps around the outer ring. This gets smooth out by Z leveling, as we can observe from figure 7. The operation substitutes a different change of tool, namely a fillet mill, needed for those specific areas.

In order to completely machine the connecting rod body, we had to set up five different operations involving five tool changes. We have begun with a profile contouring operation, designed to machine

the holes that allow connections with the piston and the crank shaft performed with a cylindrical frontal

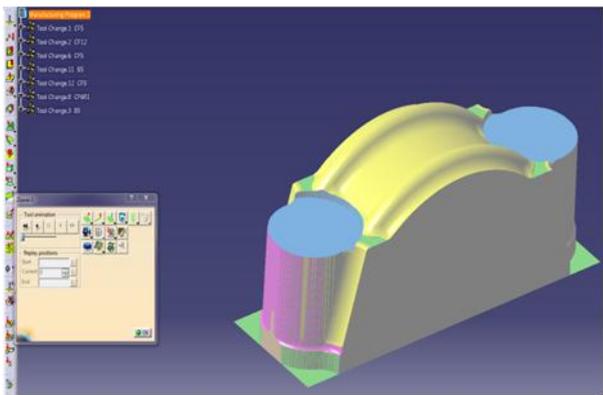


Figure 7. Z leveling transition zones of the connecting rod's head

mill of 6 mm (CF6). Then, we had to set up a roughing operation with the same type of tool (Fig. 8).

We can see all the intermediate planes that the tool has to take into account. Those ones are directly related with the number of passes that the cutter has to make, in order to complete the machining operation. Most of the connecting rod body surfaces will be covered in terms of machining by multiple Z leveling operations, more exact one for each end of the connecting rod body and one for the inner channels. Each end has transition zones with fillets at different angles which require a series of this type of operations to be designed and performed. Special attention was given to the outer ribs, which required precision and a small tool of less than 3 mm in diameter (CF2.95).

The cutter moves from one end to another in such a way that it will also give contour to the inner channel. For the piston end of the part, we needed another set of Z leveling operations (Fig. 10). As stated before, even though the inner channels were partially machined due to the number of passes that the cutter had to perform, the precision part of the process is carried out with a ball tip mill of 3 mm

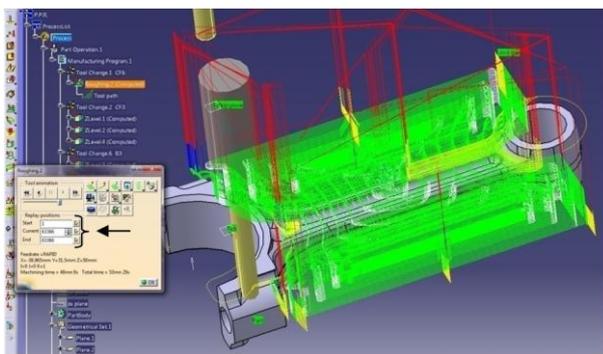


Figure 8. Roughing the connecting rod body

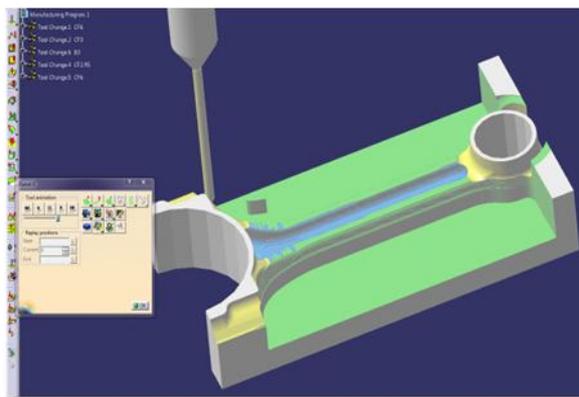


Figure 9. Z leveling crank end of the connecting rod's body

(B3), in a distinctive operation specially designed for those areas (Fig. 11).

2.3 Step 3. The output

It refers to the definition and setup of post processing operations, which will lead to the generation of the desired G code depending upon the NC centre parameters and capabilities. The *Mazak Nexus 510C* is a single column, bed-type machine, with 3 axes. It has its own postprocessor custom built which may be loaded to the software database. Post processing as well as the post processor will allow a common language between the generic internal tool path data and the *Mazak's* tool controller.

The controller was fed to *Catia* under *Part Operations* menu (Fig. 12). This "tells" the software that it should use as its post processor, the file named "*mazak.lib*", which is in fact a library that contains all required parameters that are characteristic to the NC machine.

The equipment was set to a three axis machine, which corresponds to the capabilities of the *Mazak Nexus 510C* center (Fig. 13).

Under *Numerical Control* menu, we have set proper values for *Spindle*, *Tooling* and *Compensation*. Under *Resulting NC Data* menu, we

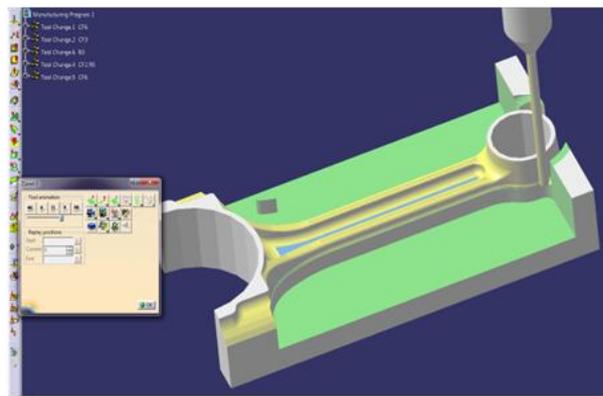


Figure 10. Z leveling piston end of the connecting rod body

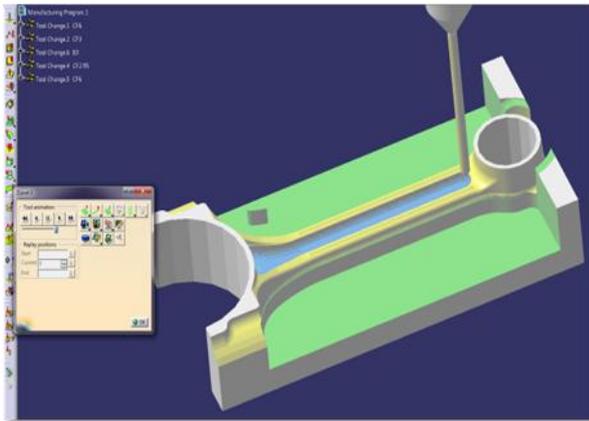


Figure 11. Z leveling the inner channels of the connecting rod's body

have specified NC code and the location for the export files. It generated a total of 25 files for both of the connecting rod's components (Figure 14).

Part of a file which was exported with the G code command lines is presented for exemplification in table 1.

Table 1. G code command lines fed to the NC center

Parameters	Command lines
:11001	Z9.703
N1 G90 G94 G64 G80 G40	G1 Z-.297 M08
G49	F1500.
(CF5)	Y-11.
N2 G91 G28 Z0	X31.
N3 G28 Y0	X32. F600.
N4 G90 G54	G3 X33. Y-10. R1.
N5 TxxTxx M6	G1 Y-9.
N6 S8500 M3	Y9. F1500.
X-14.648 Y-16.6 F5500	Y10. F600.
G43 Z70. Hxx	G3 X32. Y11. R1.
M8	G1 X31.

Fortal, the material used for machining the part, has an increased resistance, being an alloy

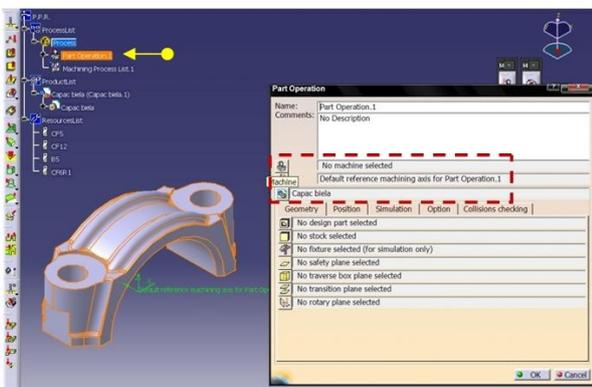


Figure 12. Part Operation menu for the connecting rod's head

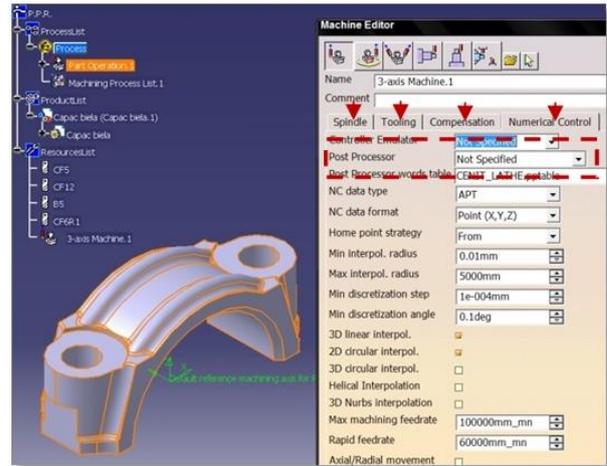


Figure 13. Post Processor definition menu for the connecting rod's head

represents just a third of the steel's one, but the material proves capable of absorbing three times more shocks and vibrations, during its elastic state [***Material's]. A comparative evaluation in terms of visual similarities or differences between the original forged connecting rod and the NC machined one may be observed in figure 15.

3 CONCLUDING REMARKS

This paper highlights some of the technical issues that can interfere in the transition procedure between a CAD environment displaying a 3D model and a NC command center, by means of which we may obtain a corresponding physical replica through NC driven machining technology. The authors have presented some steps required by the process, marking the most important ones, in terms of setup, parameters or required functions. In case of the connecting rod head, we have defined seven operations which involved every time when tools had to be changed, in order for the proper

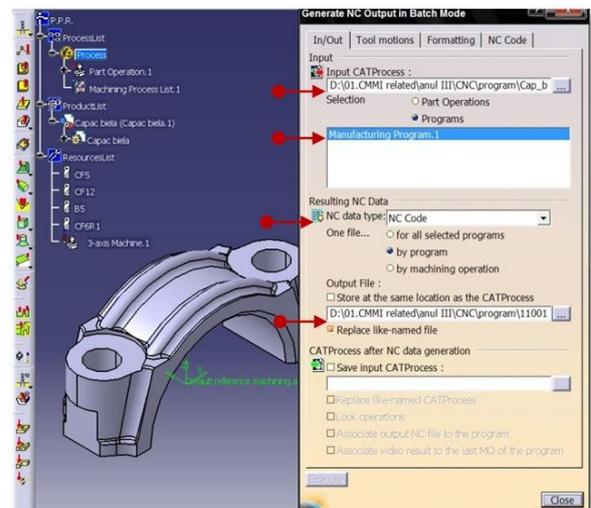


Figure 14. G type NC Code generation for the connecting rod's head

mainly used in aeronautics. Its Young module value



Figure 15. Connecting rods physical models.

- a) The original forged one;
b) The NC machined one

machining operation to take place. This translated into a great amount of both computational and processing times, as well as machining times.

The most sensitive areas were the transition between fillets and inner surfaces, as well as the ones that surround the outer rings with inner holes that are destined for bolts. Those areas are inclined at different angles and have different fillet radiuses between them and the rest of the part geometry. The best fitted function for this type of geometry is considered to be the Z leveling, as it is capable of not only machine the specified areas, but also smoothes out the entire surface. In case of the connecting rod body, the same function was chosen in order to deal with sensitive areas such as the filleted transition zones at both piston and crank end of the part, but also the inner channels, not to mention the outer fine ribs, which stretch along the entire part length. The connecting rod has undergone a series of machining operations that required both technical skills and knowledge in setting up the guidelines, planes and the areas to be manufactured after each operation has ended.

The partnership provided a rich technical background in setting up the NC center, as well as getting the data from the CAD environment to be properly read and interpreted by the Mazak center. The paper shows that the technology is applicable and more than that, it becomes a common part of the whole mechanical related

system. Not only that we have obtained a physical model, but, in terms of costs and time, we have reduced greatly the amounts that would have been required in order to perform an optimization procedure and then translate it into reality. The study highlights the advantages of this technology as it permits for a part to be scanned, optimized by means of FEA or any other means and then machined to a full scale replica of the original model. However, in this case, the next step is to generate by means of CAD tools, the mold which will contain all the geometrical features of the optimized model of the connecting rod and then by means of either NC driven machining or rapid prototyping to obtain a physical model. This will allow a manufacturer to forge the optimized model, in order to gain the same mechanical properties as the original scanned model.

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