IMPROVEMENT OF MACHINING EFFICIENCY DURING TURNING OF ENGINE BLOCK MADE OF INCONEL 718 ALLOY

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ABSTRACT

Paper presents some investigations concerning FEM simulation analysis and optimization of turning process of the external engine block surface. As a part of examinations carried out, selected turning operation of upper flanges were analyzed. These concerned facing, external and internal turning. To conduct the feed speed optimization process a force model was built which enabled to calculate cutting forces values depending on cutting parameters. The optimization research had the aim to stabilize the time course of value of cutting forces taking place during machining.

Keywords: turning, Inconel 718, optimization

INTRODUCTION

Modern metal constructions, especially in aerospace industry demand a basic understanding of the mechanical behaviour of materials [1-4]. The modelling of metal cutting has proved to be particularly complex due to the diversity of physical phenomena involved, including thermo-mechanical coupling, contact/friction and material failure [5]. Through the use of simulation technologies, the properties of the materials are intensively considered [6]. The complex properties of metal alloys structures present significant challenges during their manufacturing processes. For this reason, the proper material model applied in the simulation model of machining is an essential tool to analyse the complex behaviour of materials under the high loads, high temperature and quick changes of loads.

This paper presents simulation researches of the aeroplane part surface turning. The shape and dimensional analysis of machined surface of the engine block unit of cylindrical shape and wall thickness about 10 mm, Fig. 1 was performed.

Fig.1.
Geometry of the machined part

After initial analysis of machining operations it was noticed that there is a chance to increase cutting speed reducing the tool life to the value indispensable for performing necessary operations. It is also necessary to monitor simultaneously the influence of proposed changes on the shape and dimensional accuracy, roughness of machined surfaces and the stability of Machine tool – Tool - Holder – Workpiece (MTHW) configuration.

Changes of the feed value are possible under the condition that the increase does not cause excessive cutting resistance which can influence the geometry deformation of the machined block. To conduct the feed speed optimization process a force model was built which enabled to calculate cutting forces values depending on cutting parameters. As a part of investigations, selected turning operation of upper flanges were analyzed. These concerned facing, external and internal turning. The analyzed surfaces presents complex geometric form. They consist, among others, of under cuttings and foldings with small radii. The flanges of the analyzed part are oriented concentrically and they are in a small distance from each other. This causes difficult access for cutting tools. Fig. 2 shows the geometry of semi-finished part and tool paths for turning operations.
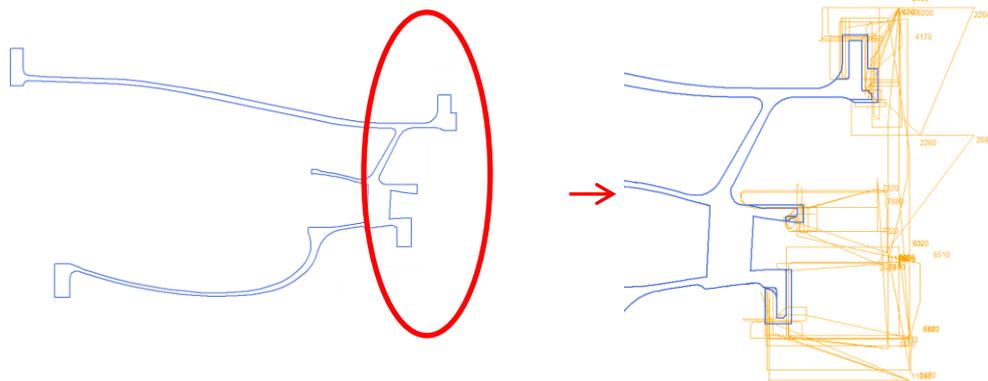

Fig. 2.
Tool paths for turning operations

For roughing operations an insert RNGN120700T01020 (Fig. 3), grade KY1540 together with tool holder (Fig. 4) were used.
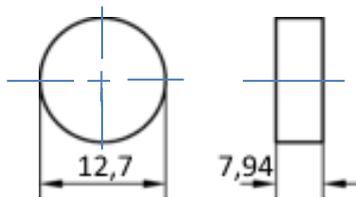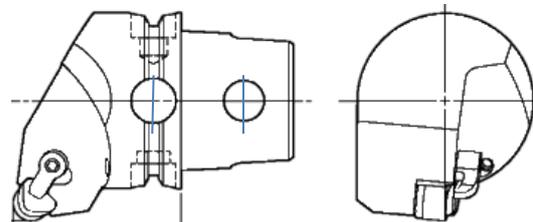

Fig. 3.
Insert RNGN120700T01020

Rys. 4.
Tool holder

Cutting parameters used in turning were as follows: v_c=200 m/min, feed f=0.15 mm/rev. Spindle rotational speed was limited to n= 350 rev/min. For finishing turning an insert RPGX090700E, grade KY1540 (Fig. 5) and a tool holder (Fig 6) were used.
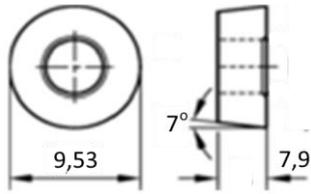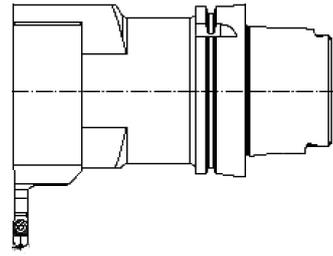
Fig. 5
Insert RPGX090700E

Fig. 6
Tool holder

Cutting data were as follows: v_c=160 m/min, f=0.13 mm/rev. Selected cutting inserts are produced by Kennametal. Recommended cutting parameters are; cutting speed v_c=140-320 m/min and feed f=0,08-0,6 mm/rev. Cutting parameters applied were in the range recommended by the tool manufacturer. The engine block unit is machined on the CNC five axis machining center. Turning is performed with the utilization of (C) rotational axis, by means of which the main cutting movement is realized and two translational axes (X, Z). Due to the thin wall nature of the workpiece, as a result of cutting forces influence, geometric deformation can take place which leads to incorrect execution of machined surfaces. During thin-walled parts machining, the important role plays the value levels of the components of resultant cutting force.

As a result of analysis and practical tests it can be stated that good results can be obtained by graduated alternate machining, one time from one side, one time from the other side of machined geometry. Optimization research was conveyed to improve the effectiveness of analyzed process. The optimization research had the aim to stabilize the time course of value of cutting forces taking place during machining.

In the first stage of simulation research cutting tools used for the flange turning were identified. Roughing cuts and finishing cuts with two cutting tools were analyzed. The first tool marked ST1 was connected with cutting insert RNGN120700T01020. The second turning tool marked SO1 was equipped with cutting insert RPGX090700E. The way of definition of the used tools was presented in Fig.7- 8. Simulation was worked out basing on the software PM [7].
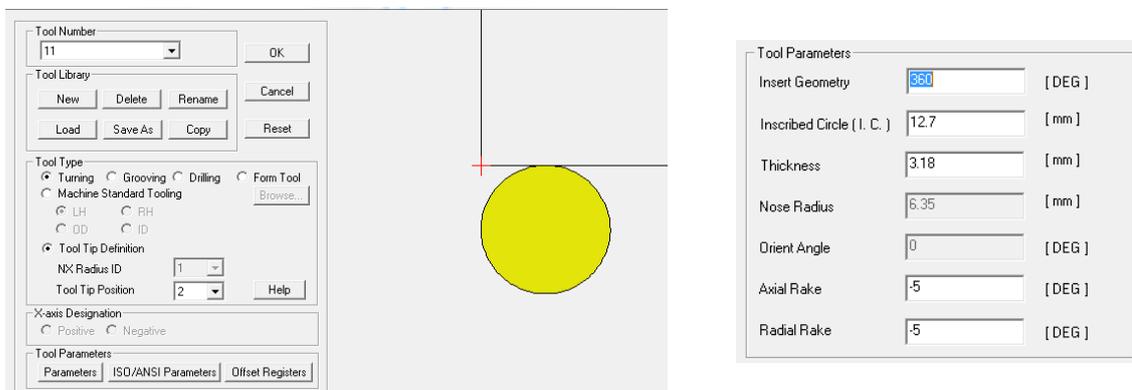

Fig. 7
Definition of ST1 tool

Tool Number
114
OK

Tool Library
New Delete Rename
Load Save As Copy
Cancel
Reset

Tool Type
Turning Grooving Drilling Form Tool
Machine Standard Tooling Browse...
LH RH
OD ID
Tool Tip Definition
NX Radius ID 1
Tool Tip Position 4 Help

X-axis Designation
Positive Negative

Tool Parameters
Parameters ISO/ANSI Parameters Offset Registers

Grooving Parameters
Insert Width 9.525 [mm]
Thickness 3.18 [mm]
Max. Groove Depth 10 [mm]
Left Corner Radius 4.7625 [mm]
Right Corner Radius 4.7625 [mm]
Left Clearance Angle 2 [DEG]
Right Clearance Angle 2 [DEG]
Bottom Relief Angle 0 [DEG]
Orient Angle 180 [DEG]
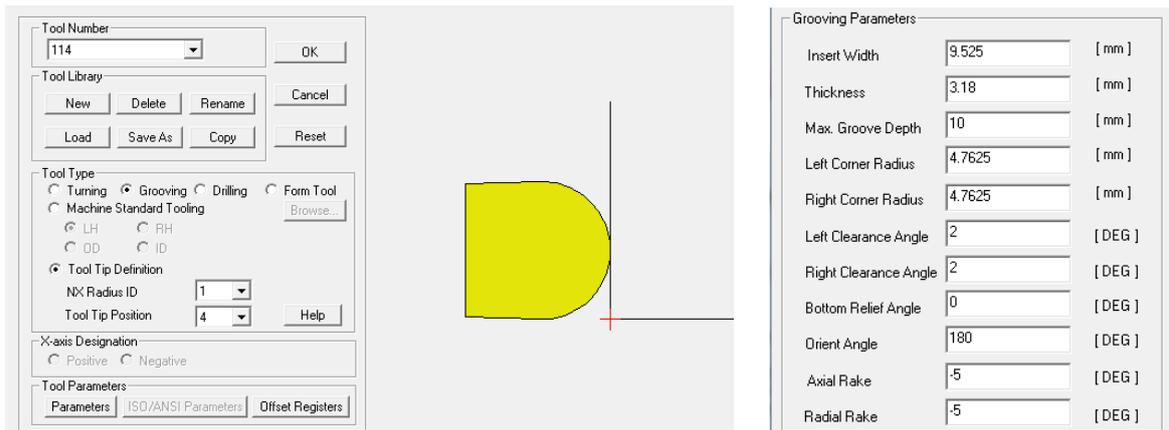Axial Rake -5 [DEG]
Radial Rake -5 [DEG]

Fig. 8
Definition of SO1 tool

In the next step of simulation research a semi-finished product and its material were defined. A semi-finished part was the blank model prepared in STL format with predefined co-ordinate system compatible with CNC machine tool system. The workpiece was made of Inconel 718 alloy. For the calculation, the material model of this alloy, implemented in the utilized program was used. Numerical calculation concerning value of the components of cutting force and metal removal rate during flanges turning were performed.

In the next step the optimization of feed speed was carried out. It was done to stabilize the time course of cutting force components during machining period. Simultaneously, maximum values of allowable feed speed were limited so as roughness of machined surfaces was not deteriorated. As a optimization criterion, value of tangential force was selected. It was set in such a way that its value was equal to the average value calculated for each of the tools used.

SIMULATION AND OPTIMIZATION OF TURNING OUTER SURFACE OF THE EXTERNAL FLANGE REALIZED BY ST1 TOOL

Based on the material model, calculations were made of the component values of cutting force occurring during machining of the part of the body external flange. The optimization of feed speed was also performed with the aim to achieve tangential components force value in the range 1100-1200N. Definition window of machining optimization parameters and a tool path for turning outer surface of the external flange realized by ST1 tool is presented in Fig. 9.

Figure 10 presents the change of value of the tangential component of cutting force during optimized and not-optimized machining process.
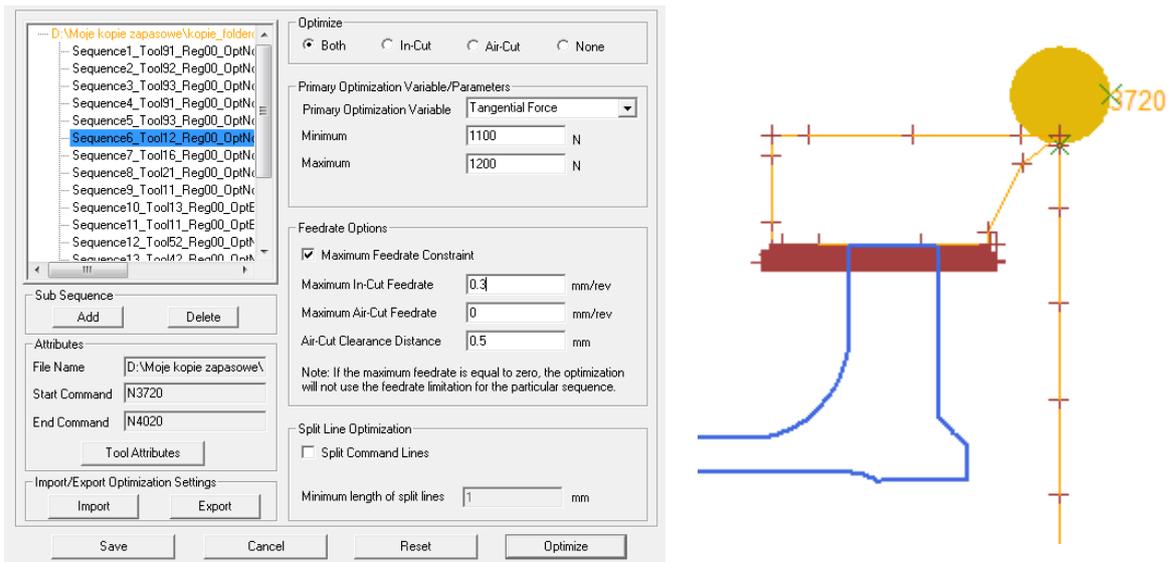
Fig. 9

Definition window of machining optimization parameters and tool path for turning outer surface of the external flange
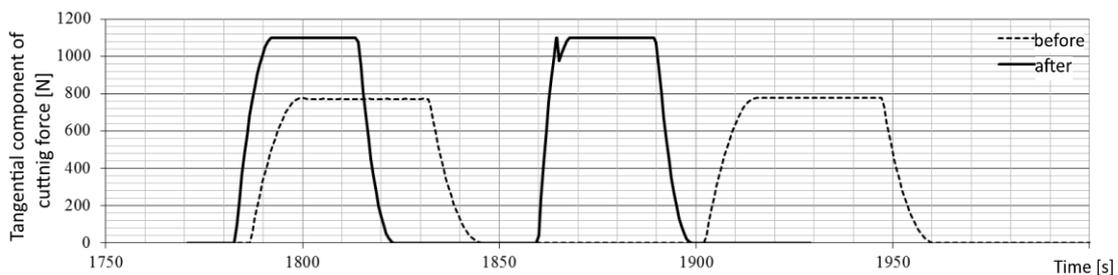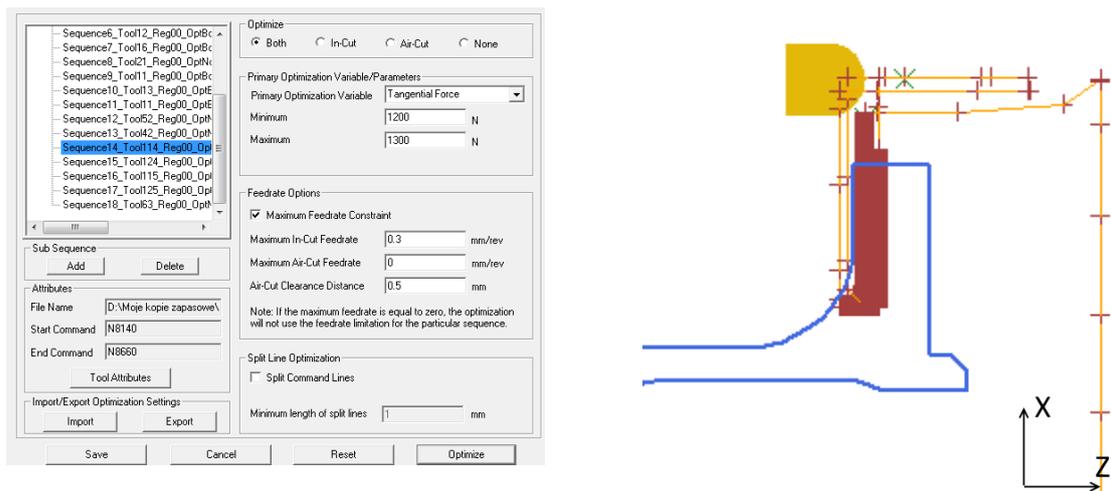

Fig. 10

The time course of the tangential component of cutting force during turning outer surface of the external flange

The result of the optimization was an increase of maximum value of the tangential components of cutting force from 710 N to 1100 N. Conducting the optimization process resulted also in the reduction of cutting time about 75 s. In the following figures (Fig.11-12) changes in metal removal rate and chip thickness can be observed.

Fig. 11

The changes of metal removal rate value during turning outer surface of the external flange

Fig. 12

The changes of chip thickness during turning outer surface of the external flange

SIMULATION AND OPTIMIZATION OF TURNING FACE SURFACE OF THE EXTERNAL FLANGE REALIZED BY SO1 TOOL

Based on the material model used, calculations were made of the component values of cutting force occurring during machining of the part of the body external flange realized by SO1 tool. The optimization of feed speed was also performed with the aim to achieve tangential components force value in the range 1100-1200N. Definition window of machining optimization parameters and a tool path is presented in Fig. 13.

Fig. 13

Definition window of machining optimization parameters and tool path for turning face surface of the external flange

Fig. 14 presents the changes of value of the tangential component of cutting force taking place during optimized and not-optimized machining process.
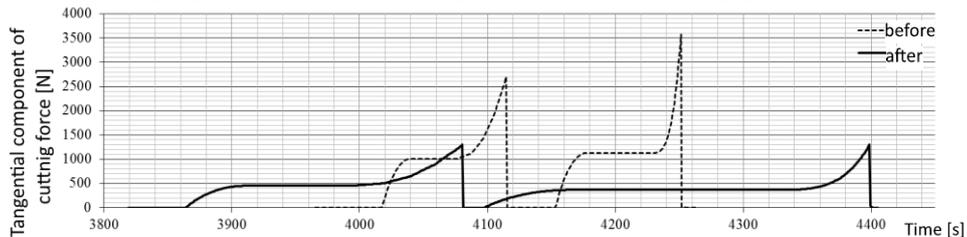

Fig. 14

The time course of the tangential component of cutting force during turning face surface of the external flange

As a result of the optimization is limited maximum force value of the tangential component of cutting force. The value was reduced from 3600 N to 1250 N. Optimization process also resulted in prolonged cutting time about 290s. The following pictures (Fig.15-16) show the changes of metal removal rate (MMR) and chip thickness in the course of time.
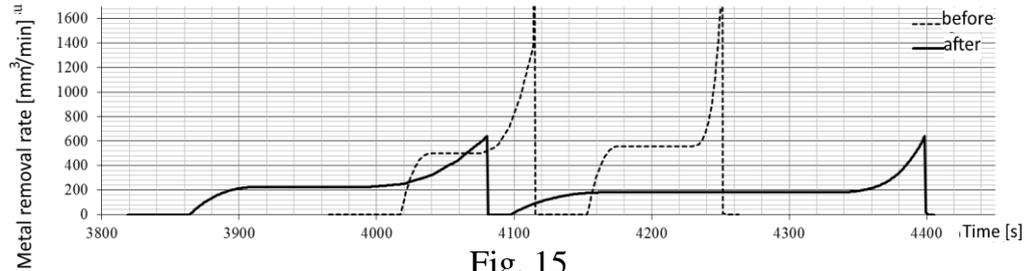
Fig. 15

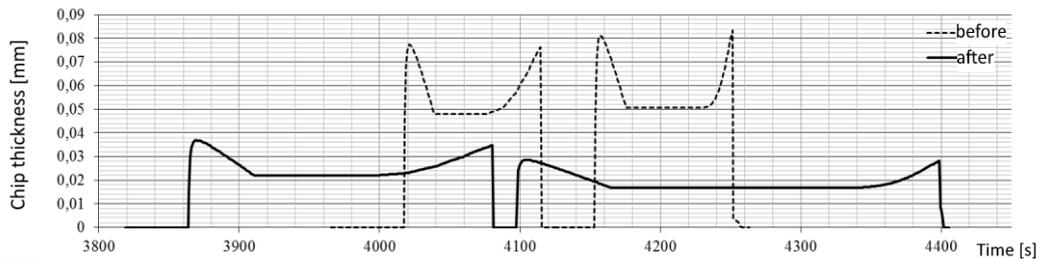The metal MRR value during turning face surface of the external flange

Fig. 16

The changes of chip thickness during turning face surface of the external flange

CONCLUSIONS

As a result of the optimization the expected goal was achieved. This concerned stabilization of the time courses of cutting force components for turning operations with ST1 and SO1 cutting tools. Time of cutting for optimized process for ST1 tool was shortened by 75s.

In contrast, time of cutting for optimized process for SO1 was extended by 290s. The whole cutting process for optimized code was extended by 215s which is 3.8% the percentage of machining time with not-optimized code which is 92 min. 54 s. Fig. 17 presents the time courses of the tangential component of cutting force for the whole optimized and not optimized machining process.
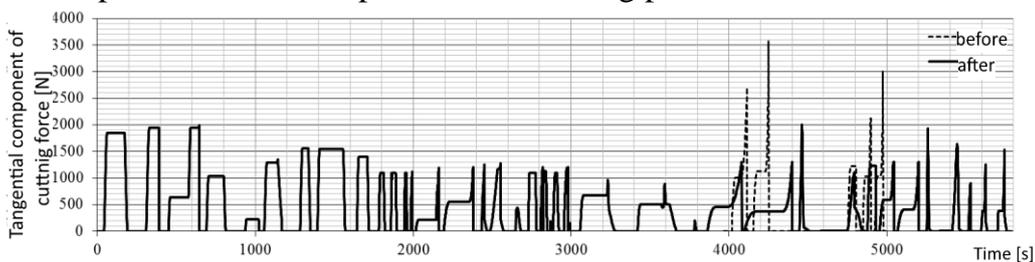
Fig. 17

The time course of the tangential component of cutting force during turning flanges surfaces of the body

The following pictures (Fig.18-19) shows the changes of metal removal rate and chip thickness in the course of time during machining process of body flanges.
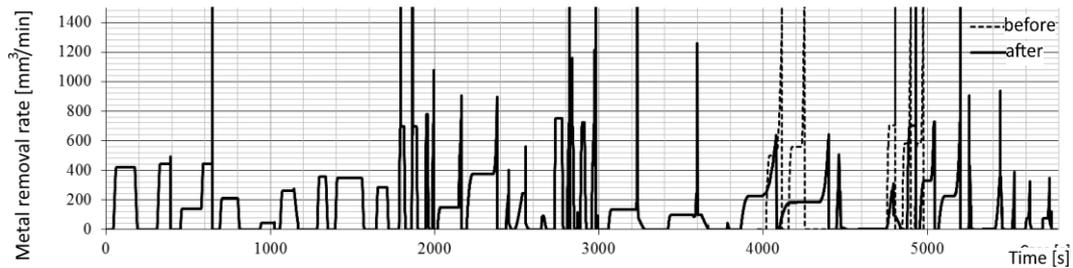
Fig. 18

The changes of metal removal rate value during turning flanges surfaces of the body
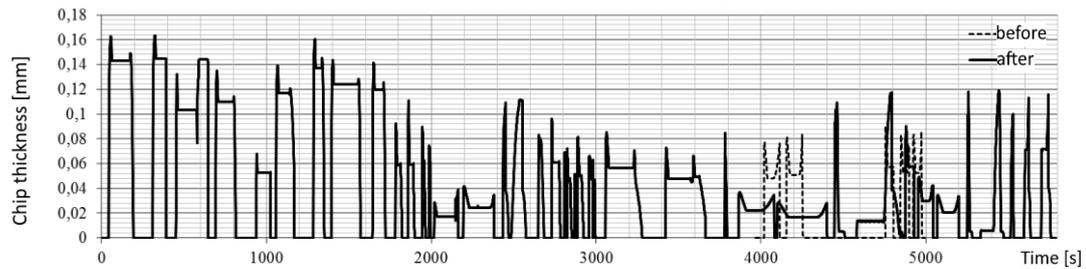

Fig. 19

The changes of chip thickness during turning flanges surfaces of the body

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