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Modeling a repair machining of a rotary kiln tire

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Abstract. The paper considers the process of edge cutting machining applied to the running surface of a defective-form kiln tire with portable machines without shutdown of cement clinker production. Conditions are formulated for geometry generation; related changes in reference surfaces are defined. These features are integrated into an algorithm aimed at minimizing deviation of the kiln tire from circular profile when modeling its repair.

1. Introduction

Currently, the competition in maintenance and repair of process equipment is growing deeper and deeper. According to open data, there are hundreds of small and medium enterprises around the globe that provide services in machining tires and rollers of rotary kilns with portable machines [1, 2]. Mobile technologies are actively developed by Phillips Kiln Services, the leading service provider in the cement industry [3].

At the same time, there is a supply shortage in meeting demand for machining related to rectifying form defects of the tires. This process is also understudied in the theoretical domain. Peculiarities of interaction between the tool and the tire surface being machined prevent fully employing capabilities of specialized CAM-CAE systems. Thus, solution of problems aimed at increased processability of the repair treatment of rotary kiln tires requires improvement of existing [4–6] and development of new calculation models of geometry generation.

2. Conditions for integrating features of attachable machines in a single calculation model

The paper [5] considered flat kinematic model of repair machining of a tire. It is based on holonomic relations in the system that includes attachable machine, tool, tire, kiln thrust rollers. In the model, the tool 4 (Figure 1) is fixed at the stand of the stationary guide of the UVS-M machine, mounted symmetrically with respect to rollers' pivot centers O_1 and O_2 . The tire 1 is referenced along the running surface of the thrust rollers 2 and 3. Let us consider a possibility of using this model for machining a tire with different attachable machines. As it is known from open sources, they may be divided into two groups according to their design.

The first group will include the attachable machines mounted at the foundation of the roller carriage to the right or to the left of the tire, which performs a complex plane-parallel motion under the influence of its defect of form. In this case, tool 8 is fixed in the dynamic self-mounting support (DSS) (Figure 1) and together they may move with respect to stationary Cartesian coordinate system $Y_1O_1X_1$ while keeping the same position with respect to the machined surface as the tool 4 in the calculation model. Common features of machines in this group are that the tool 8 interacts with the tire 1 at the surface area between the points of its contact with tracer rollers 6, 10 and it is constantly in the same plane as they



are. Thus, geometry generation will be influenced only by the distance DC , peculiarities of tracer rollers referencing along the machined surface and tolerance in all the parts influencing the position of the traverse 9.

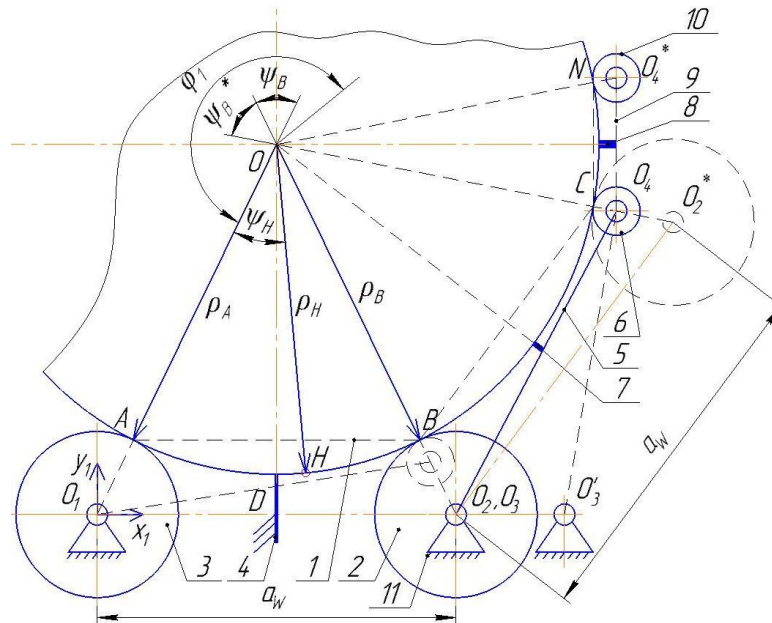


Figure 1. Variants of tool location: 1 – tire; 2 and 3 – thrust rollers; 4 – at the UVS–M machine; 5 – arm; 6 and 10 – tracer rollers; 7 – at the MAM machine; 8 – at the DSS machine; 9 – DSS traverse (its connection with the foundation 11 is not shown).

The second group will include the designs where the whole machine is fixed at a movable arm (movable arm machines, MAM). Thus, the position of the tool 7 (Figure 1) is determined by the position of the arm 5. Interaction between the tool and the surface being machined takes place between the points B and C , where the tire touches the kiln thrust roller and the tracer roller, respectively. The BC chord changes when the position of arm 5 changes. During the machining, the distance between the tire cross-section plane where the tool is located and the parallel tracer roller plane is continuously changing. Thus, unlike in the first group of machines, here the geometry generation will be also influenced by the peculiarities of referencing the tire on the thrust roller.

Providing that the design of DSS and MAM machines provides identical movement of the machinable surface with respect to the tool as the UVS-M machine, all the listed variants of attachable machines may be considered within a single kinematic model.

In MAM machines, this condition holds if the O_3 joint of the arm 8 (figure 1) coincides with the pivot center of the thrust roller 2, while the tool 7 is located at the middle of the BC chord. Total similarity is provided in a case where $BC=AB$ and $O_3O_4=O_1O_2=a_w$. In this case, the results of calculations for UVS-M and MAM are going to be identical. If $O_3O_4 \neq a_w$, then the scope of the indicator diagram is going to change during the modeling.

Besides, quantitative evaluation of tire profile geometry generation features requires considering three special cases of machining related to the influence of various referencing modes: 1) along the same unchangeable surface (two-side machining at MAM or machining with the depth of cut at least equal to the wobble as measured in the middle between the thrust rollers); 2) along the profile obtained at the previous pass (single-side machining with UVS-M); 3) along the surface that is changing during the cutting (DSS); 4) along three different surfaces, alternating depending on the cutting path (single-side machining at MAM).

With this in mind, the calculation model algorithm (Figure. 2) was changed to take into account the referencing provided in the basic data. To that end, in addition to the radius vector $\rho=\rho(\varphi)$ of the initial profile (here φ is the polar angle in the coordinate system of the tire profile with the pole in the point O), radius vectors $\rho=\rho_1(\varphi)$ and $\rho=\rho_2(\varphi)$ are added, varying in the same polar system of coordinates with the pole in the point O (Figure 1) during the current and previous pass, respectively. In the beginning of the calculations, it was assumed that: $\rho_1(\varphi)=\rho_2(\varphi)=\rho(\varphi)$.

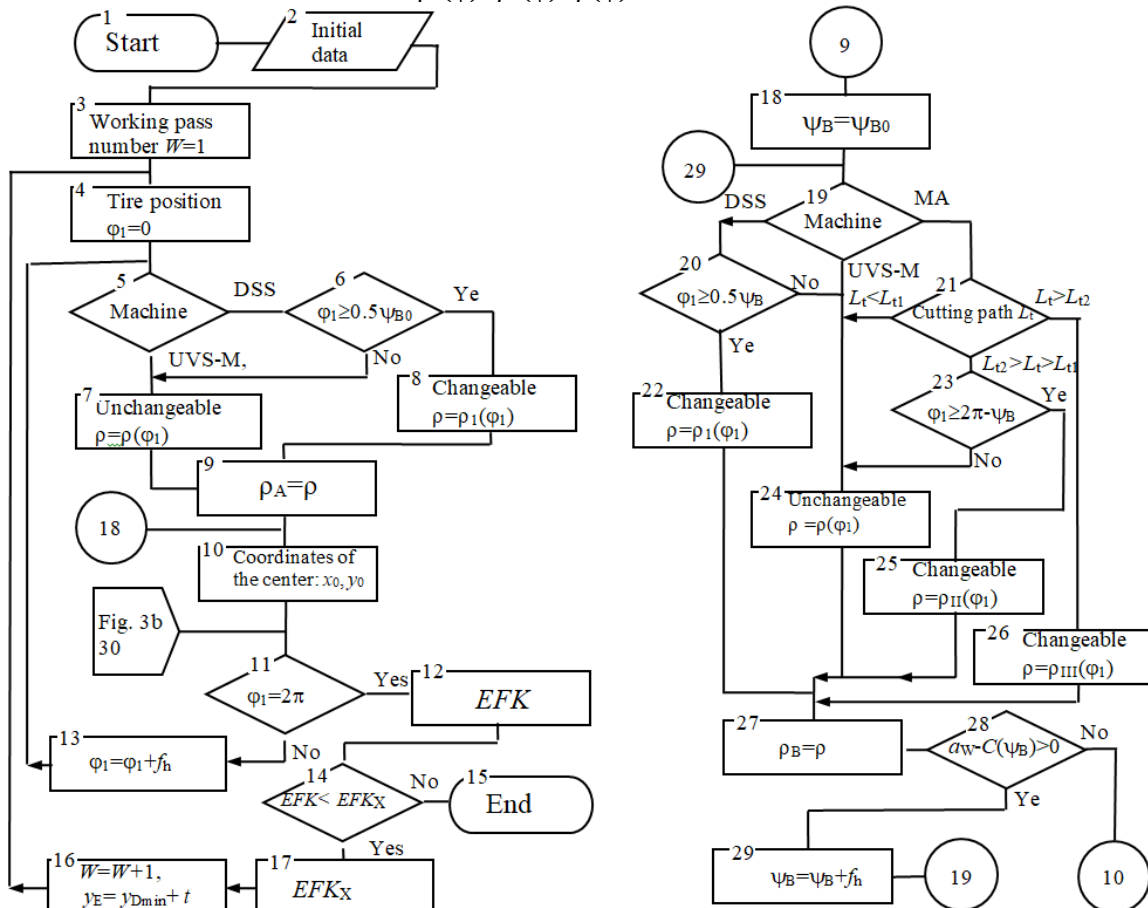


Figure 2. Flow chart of the algorithm to calculate tire profile geometry generation for tire repair machining with attachable machines: ψ_{B0} is the central angle for the nominal tire profile; L_{t1} and L_{t2} are the components of the cutting path with $L_{t2}=B-L_{t1}$, where B is the length of the tracer roller; $C(\psi_B)$ is a calculated distance O_1O_2 ; EFK_X is the minimum deviation from roundness.

Then, when determining the x_0, y_0 coordinates of the tire center, profile radius used for the corresponding referencing was substituted into the equation: $\rho=\rho(\varphi)$, $\rho=\rho_2(\varphi)$ or $\rho=\rho_1(\varphi)$. In subsequent machining modeling, only $\rho=\rho_1(\varphi)$ were substituted into the equation, while at the end of each pass $\rho_2(\varphi)=\rho_1(\varphi)$ was reset. During the calculations (Figure 2), the features of referencing were determined depending on the design of the attachable machine. For DSS machines, it was assumed that $R_1=R_2=r$ (r is the radius of the tracer roller), $\rho_A=\rho_1(\varphi_1)$ and $\rho_B=\rho_1(\varphi_1+\psi_B)$. The functions $\rho_A=\rho_2(\varphi_1)$ and $\rho_B=\rho_2(\varphi_1+\psi_B)$ were used to formalize the referencing when machining the tire with the UVS-M machine with $R_1=R_2=R$ (R is the radius of the tracer roller) or with $R_1=R, R_2=r$ for two-sided machining with MAM. In these cases, it was assumed that in all other sections of the tire, increase in the cutting path will lead to a profile identical to that in the calculation model plane related to the cross-section and passing through the points O_1, O and O_2 (Figure 1). Thus, in the end of each working path, $\rho_2(\varphi)=\rho_1(\varphi)$ was reset with $\varphi=0\dots 2\pi$. In case of a single-side machining with the MAM machine, for each tire

position, $R_1=R$, $R_2=r$ and $\rho_A=\rho_2(\varphi_1)$ (Figure 2), its profile $\rho_I(\varphi)$, $\rho_{II}(\varphi)$, $\rho_{III}(\varphi)$ was determined in three cross-sections, respectively: in the beginning with $\rho_B=\rho_2(\varphi_1+\psi_B)$, in the middle (when the tool and the tracer roller are in the same plane) with $\rho_B=\rho_1(\varphi_1+\psi_B)$ and in the end of the working pass with $\rho_B=\rho_{II}(\varphi_1+\psi_B)$. In the end of each working pass, it was assumed that $\rho_2(\varphi)=\rho_{III}(\varphi)$, $\rho_1(\varphi)=\rho_I(\varphi)$ with $\varphi=0...2\pi$.

3. Modeling the interaction between the tool and the material of the tire

The kinematic model [5] considers the repair machining in the cross-section plane of the tire. Interaction between the tool and the tire material (Figure 3) is represented with the segment DE (projection of the tool's cutting edge). The location of the tool tip with respect to the O_1X_1 axis (figure 1) for a machining pass number W :

$$y_E = y_{Dmin} + t, \quad (1)$$

where t is the depth of cut, y_{Dmin} is the minimum of the indicator function $y_D=f(\varphi_1)$ at the previous machining pass with the number $(W-1)$, φ_1 is the tire rotation angle, $y_{Dmin}=y_{D0}$ at $W=1$, y_{D0} is the coordinates of the point D before the start of the machining.

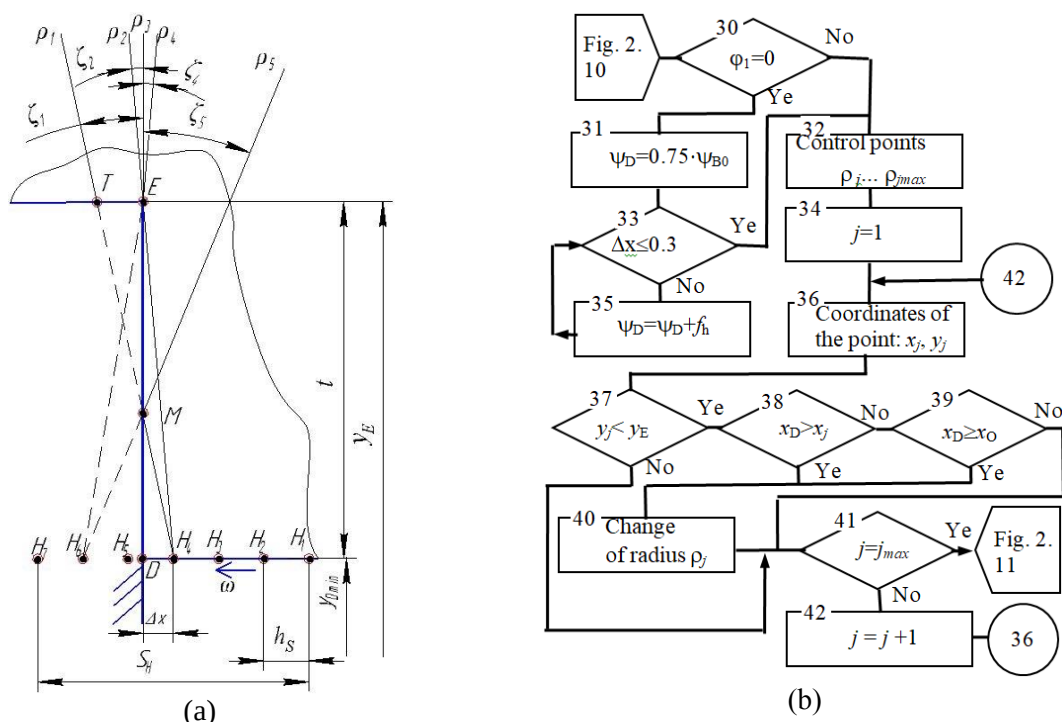


Figure 3. Checking for possible contact between the tire and the tool: a) computational model of geometry generation; b) flow chart of the calculation algorithm; ω is the angular velocity of the tire.

It is assumed, that the tire material removal depends on the coordinates y_D, x_D (in the Cartesian system of coordinates $Y_1O_1X_1$, Figure 1) of the point D and when simultaneously meeting the following conditions:

$$y_E(\phi_1) > y_D(\phi_1); \quad (2)$$

$$x_D(\varphi_1) \leq a_w \cdot 0.5; \quad (3)$$

there is a change in polar radius $\rho_1(\varphi)$ or $\rho_2(\varphi)$. Here, a_w is the distance between the pivot centers of the thrust rollers (figure 1). To provide validity of the calculation results, another condition shall hold: each point of the external surface of the profile participates in checking the possible contact with the tool during a single rotation:

$$\max(i)=\max(k)=2\pi/f_h, \quad (4)$$

where f_h is the angular increment of the tire profile $\rho(\varphi)$, i is the index of the radius vector in a one-dimensional array of already checked points, k is the number of the current tire position $k=(1+\varphi_1/f_h)$.

Then, when these conditions are satisfied and the point D (figure 3) coincides with the cutting edge of the instrument the radius of the machined surface is:

$$\rho_3'(\varphi_1+\psi_D)=\rho_3(\varphi_1+\psi_D)-DE.$$

If the point is in the point H_6 at the moment of checking the contact with the tool, then with $\rho_{46}((\varphi_1+\psi_{46}))$ we may obtain the length increment $H_6E>DE$ of a segment being cut from the area:

$$\rho_{46}'(\varphi_1+\psi_{46})=\rho_{46}(\varphi_1+\psi_{46})-H_6E.$$

Such a substitution is valid in case of an adequately determining the locations of the tire center and the point H_6 . For the point H_6 , this pertains also to a more general case with $\rho_{56}(\varphi_1+\psi_{56})$ and the angle ζ_5 :

$$\rho_{56}'(\varphi_1+\psi_{56})=\rho_{56}(\varphi_1+\psi_{56})-H_6M. \quad (5)$$

The obtained result is not to be deemed final. If we do not take into account the possibility of a change in radius $\rho_{56}'(\varphi_1+\psi_{56})$ during the subsequent movement of the tire and at once translate its end to the point E , this will lead to an error depending on the angle ζ_5 and the length of the segment ME . Then, besides obtaining an unreliable assessment of the machined surface, this error may disturb the monotonicity property of the function $\rho(\varphi)$, influencing the stability of the calculation process and preventing analysis of the geometry generation at subsequent machining passes.

Besides, there may be such positions of the tire, where cutting removes some tire material not located at the external surface. For example, for the point H_4 with $\rho_{24}(\varphi_1+\psi_{24})$ the condition (3) is not met, but at the point E we find the tool tip, and not the tire material. Continuation of the rotation with the radius of $\rho_{14}(\varphi_1+\psi_{14})$ at an angle of ζ_1 and no movement of the point H_4 will lead to removing the material at the segment MT .

Thus, meeting the conditions (2), (3) and (4) is not sufficient for obtaining reliable calculation results, meaning, formalization of the cutting process in the initial kinematic model requires the following elaborations: 1) removing the uncertainty due to tire material identification; 2) determining the movement of each point of the tire profile in the vicinity of the cutting edge (Figure 3a, projection DE).

In the first case, the representation of the material as a series of discrete points at the rolling surface shall be substituted with an aggregate of points filling the area above and to the right of the lines ET and DE , respectively (Figure 3). To that end, we are going to assume that the material is uniformly distributed along each polar radius of the tire profile $\rho=\rho(\varphi)$. Taking into account that for a nominal radius of 2425 mm and small angular increment, e.g., $f_h=0.0001$ rad, the distance h_s between the profile points at the external surface of the tire is at most $h_s=0.243$ mm, we may assume that it is the same at the depth of cut t . It will allow considering the machining as a result of removing the material from the points at the tire profile radius coinciding with the projection of the tool.

The second elaboration is related to a necessity of defining such a number $j_{\max}$ of the tire positions that is sufficient for reliable definition of the profile $\rho_1(\varphi)$ and meeting the condition (4). Thus, initially, with $\varphi_1=0$, $k=1$ we use a numerical method to find a point H at the tire surface, which coincides with the projection DE of the tool within a margin of error Δx with $\varphi=\psi_H$, $k_H=(1+\psi_H/f_h)$. Then, we set an odd value of $j_{\max}$ and find the distance S_H between the terminal points of the segment of the tire surface being checked for a possible contact with the tool:

$$S_H=(j_{\max}-1) \cdot h_s. \quad (6)$$

We position S_H in such a way that the point H coincides with the middle point of the S_H . Then, the polar radii of the profile points, which shall participate in the check for a possible contact with the tool for this position of the tire are:

$$\rho_j=\rho(\psi_H+(c+1-j) \cdot f_h),$$

where $-c=(j_{\max}-1) \cdot 0.5$, $j=1 \dots (c+1)$. After rotating the tire at an angle $\varphi_1=c \cdot f_h$ and further in accordance with the condition (4), it is necessary to consider the radii of the following points with $j=1 \dots j_{\max}$ for each location: $\rho_j=\rho(\varphi_1+\psi_H+(c+1-j) \cdot f_h)$.

The results of the checking calculations show that selection of $j_{\max}$ shall be rationally related to the depth of cut t . Then, for $S_H = t \cdot n \geq 1$ mm from (6):

$$j_{\max} = 1 + S_H/h_s = 1 + (t \cdot n)/h_s.$$

For instance, for $t=0.5$ mm, $n=2$, $h_s=0.24$ mm, we obtain $j_{\max}=5$. For $t=2$ mm, $n=1$, $h_s=0.24$ mm, we obtain $j_{\max}=9$.

In the calculation algorithm (Figure 3), the check for a possible contact with the tool is always performed instead of the condition (3), if the end of the vector ρ_j is located in the area limited with the straight lines DE and ET . Otherwise, only in cases where the center of the tire is to the left or coincides with the straight line DE .

4. Conclusion

Identification of design peculiarities of attachable machines that influence the geometry generation of the tire profile allows considering them within the framework of a single kinematic model. At that, additional complication of the calculation algorithm is related to a necessity of considering the influence those changes in the referencing surfaces during the machining have over the tire profile geometry generation.

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References

- [1] Pogonin A A 2004 *Restoring the Accuracy of Large-Size Components Using Attachable Machining Modules* (Belgorod: Publishing house of RSTU named after V.G. Shukhov) 190 p
- [2] Gebhart V 2006 How to repair thrust worn rollers and tires of cement kilns *Cement and Its Applications* [in Russian – Cement i Ego Primenenie] **6** 64-69
- [3] Ross D H 2015 Stable operation of kiln is the foundation of its reliability *Cement and its Applications* [in Russian – Cement i Ego Primenenie] **2** 108-110
- [4] Shrubchenko I V, Kuznetsova I I and Shrubchenko I V 2012 *Increasing Processability of Machining of Large-Size Composite Tires by Means of Minimizing Required Allowance* (Belgorod: BSTU) 156 p
- [5] Goncharov M S, Goncharov M S, Khurtasenko A V and Shrubchenko I V 2017 Peculiarities of geometry generation during the repair processing of tires with portable machines *Annals of Irkutsk State Technical University* [in Russian – Vestnik Irkutskogo Gosudarstvennogo Tehnicheskogo Universiteta] **21(7)** 10-25
- [6] Pelipenko N A and Sanin S N 2013 Describing the behavior of the center of mass of a tire with mathematical modeling *Repair, Restoration, Upgrade* [in Russian – Remont, Vosstanovlenie, Modernizatsiya] **1** 46-48