Modeling of complex construction problems for randomly changing technological processes

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Summary. Modeling of complex construction problems for randomly changing technological processes occurs during the production of rubber compounds. Without a good knowledge of the technology of producing rubber compounds, durable and efficient mixers cannot be designed. The conducted industrial research has been shown that the process of mixing the raw materials varies in time and that the forces acting inside the mixer chamber are distributed randomly. During the mixing process of the chemical components, the position of the force changes inside the mixing chamber. The load on the mixer changes over time - as a result of mixing the raw materials and the pressure of the beater. After feeding the raw materials into the mixing chamber, a big concentrated force is reacted on the ram of the mixer, which over time is transformed into several concentrated forces acting simultaneously. Then, as a result of mixing raw materials, temperature and chemical reactions, a pressure acts on the walls of the chamber and the ram of mixer. The conducted research has proved that the most dangerous, from the point of view of the mechanical durability of the mixer, is the first stage of production, in which the beater is subjected to concentrated force. Then, the compactor deforms much more and it can scratch the surface leading to damage to the mixer. The conducted research allows for a much better understanding of the process and thus to carry out a variant simulation of deformations occurring during operation, and thus to improve the durability of the mixer mechanisms.

Keywords: deformation, mixer, rubber compound, modeling, randomly variable process, tribology.

1. Introduction
Closed mixers for the production of rubber compounds are complex machines commonly used in the automotive industry for the preparation of rubber compounds used in the production of tires, seals, and polymer shock absorbers. There are two main types of intermix and tangential mixing. In both cases, the mixing process takes place in a closed chamber and the rubber components are pressed from above by a suitably shaped stamp. The idea of building a mixer is presented in Fig. 1 (stamp in top and down position). The topic of the causes of damage to the mixer punch (stamp) for making rubber mixtures is not a frequent topic discussed in publications. There are only a handful of mixer manufacturers in the world that supply machines to a huge number of plants. The largest number of installed mixers are in China and therefore these issues are raised by Chinese scholars [1]. The University of Akron is one of the world's leading universities in rubber compounding and
compounding technology. Concerning the mixer rotors, a very interesting publication was prepared by a team of Tambov State Technical University employees of the factory. The authors of the article did not come across a scientific description of the problems of the wear and its causes presented in the study.

Fig. 1. Sketch of a mixer for making rubber mixtures.

2. Damage to the punch surface and mating surfaces

During the tests, the condition of all cooperating surfaces of the stamp with the tower and the chamber was analyzed. As a result of the work carried out, it turned out that the damage occurred mainly in the central part of the sidewalls (from the cooling side and from the drive side) and on the rear and front wall (from the loading side). Examples of damage to the punch are shown in Fig. 2 and scratches of the sidewall of the tower are shown in Fig. 3. Figures 4 and 5 are photographs showing the corners of the stamp. The sidewalls of the stamp showing the nicks of the lower edges of the stamp are visible
in Figs. 6 and 7. In order to diagnose and observe the rubber arrangement during loading, the rear and side inspection hatches were removed and the method of loading the mixtures into the chamber throat was observed.

**Fig. 2.** The punch was damaged in the central part of the sidewalls. Photo taken after the tower assembly has been disassembled and prior to shipment to the mixer manufacturer.

**Fig. 3.** The greatest damage to the sidewalls of the tower and the chamber occurred in the center of the walls.
Fig. 4. The corners of the stamp were undamaged.

Fig. 5. Example of an undamaged corner of the punch and damage in the form of gouging out metal in the center of the lower surface of the punch.
**Fig. 6.** Loss of material in the corner of the lower part of the stamp - in the central part of the sidewall.

**Fig. 7.** Losses of the stamp material occurring mainly in the central part of its sidewall.
3. Examination of rubber decomposition in the mixer chamber

In order to diagnose damage to the internal surfaces of the mixer, a research methodology was developed consisting of examining the "arrangement of mixed components" inside the chamber. The photos of the rubber arrangement in the throat, taken during the tests, are shown in Figs. 8, 9, and 10.

Fig. 8. Photo taken while loading the mixer (the rubber mixture in the form of a tape moves over the loading door). Photo taken from the mixer operator's working position.

Fig. 9. Made through the inspection hole in the rear wall of the mixer when loading the mix inwards.
Fig. 10. A photo of the mixture taken after closing the loading door and before lowering the stamp. The photo was taken through the inspection hole located in the rear wall of the mixer tower.

In order to observe the method of arranging the rubber mixture inside the chamber, the rear flap of the chamber was dismantled and the distribution of the mixture inside the mixer and the work of the punch was carefully observed. It can be assumed that the distribution of the mixture between the surfaces is consistent with the frequency definition of Richard von Mises. The method of distribution of the mixture can be written as the number of elementary events favoring the event \( A \) (for the English word area - the area of distribution of the mixture between the bounding walls) in \( n \) experiments (trials), the quotient is called the frequency of the event \( k_n(A) \)

quotient \( \frac{k_n(A)}{n} \) is called the event rate \( A \). The research shows that the probability of an identical distribution of the mixture is infinitely high.

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P(A) = \lim_{n \to \infty} \frac{k_n(A)}{n}
\]  

The above study allowed to change the philosophy of simulation and strength calculations as well as the propagation of the mixer punch deformation. Therefore, the process of mixing the components of the rubber mixture significantly accelerates and stabilizes after lowering the punch into the space of the mixing chamber (Fig. 11). When going down, it did not rub the inner walls of the mixer. During the kneading of the mixture, the punch performs gentle rotational movements (it floats, rises on the rubber, is pressed by hydraulic cylinders). Therefore, the research shows that for calculating the shear deformation it cannot be assumed that:

1. the force in the first phase of contact of the punch surface with mixed components always acts in the same place,
2. force will be constant in value and direction.
4. Simulation studies

According to the results of observational studies and the infinite number of layers of the mixture in the inner space of the mixer, it results that checking calculations should be performed for a very large number of combinations of forces that may occur in a complex industrial reality. Very carefully analyzed the case of wear of the internal mixer, in particular the possible causes of damage to the punch and the walls of the tower, taking into account the different variants of the device. Particular attention was paid to the possible impact of blocking the rubber lining between the loading door and the punch moving downwards. The computer simulation shows that pressing the rubber mixture with the door may bend the punch towards the rear wall of the tower. The FEM simulation result is shown in Fig. 12.

**Fig. 11.** Photo taken with the stamp in the "down" position.

**Fig. 12.** The yellow arrow shows the model of the perpendicular force that can arise when the loading door on which the rubber rests is closed. The trailing edge of the punch (the edge opposite to the loading door) can then rub the rear wall of the mixer along its entire length.

FEM simulation was performed for the case of an extremely unfavorable effect of the force occurring in the punch corner. As a result of the above-mentioned force, it twists. The stamp with its corners
should rub the sidewalls of the tower and the chamber around the corners. Scuff marks should therefore be visible at the corners of the stamp. The simulation results are shown in Fig. 13. However, such a situation did not occur in the example shown in Figs. 2 ÷ 7 because seizures and material losses occurred in other areas.

Fig. 13. The yellow arrow indicates the punch load in the corner. The punch is deformed and may rotate the punch. With the above-described punch deformation, its edges may rub the walls of the tower and the chamber.

Carried out further analysis of strain movements that may occur during normal operation of the stamp. A visual presentation of potential deformations is presented in Fig. 14. It shows that the punch flexes in the middle towards the tower wall on the cooling side and similarly towards the drive side. Fig. 15. shows the stamp as seen from above during normal operation. Fig. 16. p shows the stamp seen from the bottom (from the side of the compressed rubber mixture) deformed as a result of the forces generated during normal operation. In fig. 17. the original position of the stamp is marked with a thin white line and the shape of the deformed stamp is marked in blue.

Fig. 14. The deformation of the punch assembly that occurs when the components are mixed. With the above-described punch deformation, its edges may rub the central part of the walls of the tower and the chamber. Stress accumulation takes place on the central part (the intensity of the color indicates an increase in stresses, the "cold" color, e.g. blue and green, are less stresses causing less deformation, yellow, orange is a gradual increase in stress, and red is the maximum stress increase that can cause permanent material deformation).
Fig. 15. A deformation of the punch assembly that occurs when the components are mixed when looking down at the punch. With the above-described punch deformation, its edges may rub with the central part of the walls of the tower and the chamber. The red line (longer line) is the rear of the mixer and the green (shorter line) is the sidewall. The drawing shows the possible contact points of the punch and chamber walls.

Fig. 16. The original position of the stamp is marked with a thin white line, the shape of the deformed stamp is marked in blue, the yellow arrows symbolize the pressure exerted on the stamp during normal operation.

The FEM simulations described in the work facilitate the understanding of the phenomena related to the deformation of the punch and the entire system under the influence of stresses arising during machine operation. All the above-mentioned cases have one main common feature, that is, the concentration of stresses on the surface of the punch. As a result, the surface of the stamp is exposed to material fatigue. The quality of the surface should be impeccable. Also, the surfaces of the sidewalls of the tower, chamber throat, and loading door must be properly matched, made of a suitable material, and then properly processed. All elements must be permanently connected so that the forces generated during operation do not cause excessive deformation and lead to permanent deformation. The damages observed on the punch and the walls of the tower (especially the sidewalls - Figs. 2 ÷ 7) clearly indicate that they could not be caused by the observed jamming of the rubber mixture.
5. Conclusions

The mixer is a very expensive machine and, at the same time, of a large weight and dimensions, difficult to disassemble. Stopping the line of the mixer is always very onerous for production plants because it causes the necessity to purchase the mixture outside or limits production. The lack of reaction of the maintenance service and not stop the mixer - causes that the metal scraped fillings are inside the rubber mixture, which creates a risk that the tire, the seal may have a hidden defect. Therefore, the issue examined by the team is very important for the functioning of production plants and vehicle users, and other rubber elements.

According to the developed test procedure, during the simulation, particular attention should be paid to all possible unusual situations that may occur during the operation of the machine. In the case under consideration, the reasons for the deformation of the mixer punch were searched and it was checked whether it could be the cause of the damage presented in the photos in this paper in fig. 12. Deflecting the punch should damage the entire width of the punch and the turret. As a result of the inspection, no damage was found (damage along the entire length of the rear face of the stamp). It could happen that the mixture was partially left on the loading door, then tilting the loading door (while closing) should cause the mixture to slide inside the mixing chamber (between the rotors). If the rubber is below the punch, forces act on the punch, which deforms the punch as shown in the model in fig. 14, 15, and 16. The deformations during the normal operation of the punch are presented in the drawings (fig. 14, 15, and 16). The simulation assumed that the pressure of 20 to 50 N / cm² was applied to the lower surface of the punch.

Summarizing the arguments made so far, below we indicate the causes of damage.

1. If it were assumed that the scratches on the punch and sidewalls were caused by the rubber compound jamming and the punch shift, there would most likely be a trace along the entire length of the contact edge (the length of the punch wall would leave a mark on one of the inside walls of the tower). However, such a situation did not take place, therefore, the claims that the scratches were caused by wedging of the rubber mixture cannot be reconciled with the traces found on the walls of the stamp.

2. Increased stresses on the punch surface during operation caused deformation of the punch surface in places where seizures occurred. Excessive increase in surface stress could cause chipping of the material in the walls of the punch and loosening at the point of connection with the punch core.

3. Chipped material could get into the space between the walls of the punch and the walls of the tower, scratching the inside walls of the mixer.

4. When the punch material got between one of the walls of the punch and the tower and the punch movement began, the process of deformation of the tower assembly increased (it was intensified), which could consequently lead to the formation of thresholds on the inner walls of the mixer tower.

5. The nicks of the punch edge and the defects in the walls of the tower caused the rubber to accumulate in these places.

6. The residual rubber mixture underwent “vulcanization” and got into a good material - a rubber mixture.

References

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