Highly efficient mixing with tangential internal mixers

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Tangential internal mixers have been used successfully for over 100 years to process rubber compounds. Continuous development of the mixer has enabled the mixing process to be made ever more effective. The present article describes an often unexploited potential in terms of process engineering. By deliberately adjusting friction and the position of the rotors, further potential can be leveraged at different mixing stages. This additional function can be retrofitted onto existing lines at reasonable cost. Modern multi-layer power train concepts also help to reduce operating costs for the mixing line.

INTRODUCTION

On 19 May 1877, Stuttgart firm Werner & Pfleiderer obtained their first patent for the tangential internal mixer in what was then the German Empire [1]. Back then, tangential mixers had neither a ram nor a drop door. The mixing chamber had to be tipped to the side in order to empty it [2]. The first tangential mixers as we know them today (with a ram and drop door) were developed by F.H. Banbury in 1916 [3]. Since then, the basic principle of the Banbury mixer has been continuously developed and improved by equipment manufacturers. For instance, rotor designs have been created for different purposes within the field of rubber compound production [4]. One of these developments was N geometry (Figure 1), patented by Lasch and Frei in 1943 for general-purpose use [5]. N geometry is characterised by two large wings starting on the face of each rotor with two smaller, opposing central wings [4]. The larger of the two small wings is only 70% of the size of the large wings. This configuration provides a main effective axis for the rotors over their cross-section (Figure 2).

Today, tangential internal mixers are generally equipped with a variable-speed electric drive. The transmission of power between the electric motor and the mixer takes place by means of a multi-stage mechanical gearing (Figure 3). The last stage of the gearing does not have any further power transmission function but is needed to set the friction between the rotors and to balance out torque peaks. Torque peaks can occur for example while charging the mixer when material is grabbed by one of the two rotors. The transmission is

Figure 1. N rotors [4]

Figure 2. Schematic diagram of rotor cross-section
therefore designed to withstand torque peaks of 170% of the rated torque [6].

In the design of the power train, friction is set at a fixed value of between 5% and 20%. The length of time taken by a sequence in which the relative position of the rotors is repeated differs according to this level of friction (Figure 4). Different conditions are created in the mixer, since this relative position of the rotors is not repeated from one revolution to the next. To illustrate this, Figure 5 shows the gap widths between the red and blue rotors. By turning the rotors with 10% friction, the graph shown in Figure 6 is obtained for the gap to the central axis for both the blue and the red rotor. According to Figure 4, a sequence with 10% friction requires five revolutions. At one point during this sequence, the situation occurs where two large wings meet and contribute to a considerable reduction in the size of the gap between the rotors. This configuration leads to a high degree of shear or stretching of the material, which in turn leads to a hotspot.

Depending on the process step in rubber compound production, these shear peaks are either desirable or to be avoided at all costs. If we now break away from the idea that the rotors can only be driven with fixed friction, new possibilities open up. Figure 7 shows that if the rotors are oriented at 180° and operated at even speed, two shear peaks can be achieved per rotation. Compared with 10% friction, therefore, it is possible to increase the number of shear peaks by a factor of 10. By shifting the relative positions of the rotors, a 90° configuration can be achieved (Figure 8). The curve for the shear gaps obtained is significantly more homogeneous over a revolution. The shear load is significantly lower and therefore the risk of overheating is reduced for the compound in the mixer.

POTENTIAL FOR FRICTION ADJUSTMENT

The production of a rubber compound involves various phases. In a first step, it is often necessary to break down relatively large lumps (e.g., crude rubber, carbon black agglomerates) to create the largest possible surface area for wetting with the other ingredients of the compound. The effectiveness of this dispersive mixing depends primarily on the shear stress that is introduced. In a further step, these ingredients are broken down further or distributed randomly in the material being mixed, together with other components. This distributive mixing phase can also be made more efficient by means of higher shear stresses. Other raw materials have to be deformed or undergo laminar mixing. Since these include raw materials from the curing system, it is important to minimise shear peaks during this phase since these peaks can lead to localised overheating of the material.

Reactive mixing is another application. Silanisation in particular requires mixing at the highest possible speeds with, as far as possible, an isothermal temperature profile (no shear peaks or hotspots). The continuous
creation of new surfaces enables by-products forming during silanisation to be eliminated efficiently.

Tacky compounds are difficult to remove from the mixer as the material sticks to the rotors. This phenomenon can be counteracted by targeted temperature control of the mixer components. However, using a relative speed (friction) between the rotors is often the way to achieve more reproducible success.

If a mixing process for producing a finished compound is analysed, four phases can be distinguished. In phase 1, the material to be mixed is introduced into the mixer. The duration of this phase relates directly to the gap width between the rotors. In tangential mixers, however, this gap width is generally large enough to avoid any back-up of material. This may not be the case with intermeshing mixers. For raw materials or compounds that are difficult to feed, however, equipment is available which is installed upstream of the intermeshing mixer from the point of view of material flow and supplies it with the raw materials/compound in a suitable form. Overall, the feed phase does not represent a problem with tangential mixers and therefore the friction and positioning of the rotors have very little effect on it.

In the second phase, the masterbatch has to be plasticated and preheated so that it is ready to accept the curing system in the following step. Large amounts of energy have to be introduced in the shortest possible time in this step. An even-speed configuration with a 180° positioning of the rotors would be appropriate here (Figure 7).

In the third process step, the curing chemicals are distributed in the material being mixed. The mixer therefore contains a reactive mass, which can be activated by thermal influences. The quality of mixing in this process is often equated to the number of revolutions. It is therefore important to achieve the necessary number of revolutions in the shortest possible time at the highest possible speeds while avoiding hotspots. An even-speed configuration with a 90° rotor position is particularly suitable for this process step (Figure 8).

The mixing process finishes with the discharge of the material (generally the shortest of the four process steps listed here). This step is very important, however. It must be ensured that the mixer is emptied completely. Any residual material from a previous batch could lead to scorching in a subsequent mixing step as a result of the overall heat history, which could then be distributed uniformly throughout the current batch in the mixer. This would certainly be undesirable. The discharge result can be improved significantly in terms of process capability by means of friction between the rotors.

Figure 9 shows an overview of a mixing process for producing a finished compound. The advantages of the different configurations can be seen together with the advantages arising from modifications during ongoing mixer operation.
LAYOUT OF DRIVE TECHNOLOGY

When designing a new installation, the functions described above can be included at the planning stage. In this case, electromechanical drive concepts compete with hydraulic drive concepts. For example, Figure 10 shows a configuration for a space-saving hydraulic solution. Often, however, we must assume that these additional functions in the drive technology have to be introduced into existing structures. In other words, a tangential mixer (see Figure 3) and an existing mixer platform are already in place, with the limitations that this entails.

Electromechanical drive concepts which fulfil the supplementary functions described above often represent considerable challenges for the equipment manufacturer because of the space required by this technology, and so a suitable design must always be matched to the existing local conditions in detail. The configuration shown in Figure 10 involves extensive modifications in a retrofit project. A new rotor shaft must be procured and the mixer has to be disassembled in order to install the new rotor shaft. This comes at considerable cost, which can, however, be avoided by a set-up similar to the one illustrated in Figure 11. This layout, which was specially designed for retrofitting/conversion, can be achieved at significantly lower cost. No new parts have to be procured for the mixer and there is no need for the mixer to be disassembled and reassembled. The grey box in Figure 11 represents the space required for the disassembled electromechanical drive. In many cases, a similar plant design can also be integrated retrospectively into existing structures at reasonable cost.

The design illustrated in Figure 10 cannot always be integrated into existing structures since, starting from the position of the mixer and the downstream equipment, additional space is required on the original cooling water side of the mixer.

DRIVE TECHNOLOGY DESIGN

Electromechanical drives are usually designed with frequency converters which allow time-limited overload of the drive. The frequency converter allows the use of rotor speeds which exceed the drive’s rated range. AC drives can be operated for a limited time with an overload of up to 2.3 times the rated output. If the overload is appropriately set, up to 40% of the mixing cycle can generally be achieved with operating points above the rated output of the drive.

Since each rotor is turned by a separate power train (gear, electric motor, frequency converter) in this application, it is not possible to halve the original rated output and allocate each half to one of the two power trains because of the different loads on the rotors. In a coupled electromechanical drive (see Figure 3), the last stage of the gearing is responsible for balancing the loads between the two rotors and ensures a uniform rotational speed. To be able to achieve this, this stage of the gearing is designed to tolerate 170% torque. It is certainly not necessary to take the full 170% into account when designing the two separate power trains. However, it is recommended that allowance be made for sufficient reserves since the stiffness of the drive is dependent thereon. If the drive is not designed with enough stiffness, it cannot ensure different frictions and positions of the rotors over the whole of the mixing process.

Figure 12 shows this problem as applied to a hydraulic drive concept. Until about ten years ago, the approach to these conversions was to use two independent pump units to drive two separate hydraulic motors. For several years, however, so-called tandem pump units have been available which perform the torque-balancing task of the absent gearing. Tandem pumps are characterised by the fact that one electric motor drives two pumps. The different speeds of the two rotors are achieved by adjusting the pivoting angle of the pumps. This eliminates the need for additional power when designing the power trains. When applied to the example used here, this means that the mixer can be driven with “only” 1500 kW overall (Figure 13). The use of this tandem
Another significant optimisation of the energy utilisation factor with hydraulic designs can be achieved by using a multi-layer power train including a frequency converter. An example of such a design is illustrated in Figure 14. This shows a configuration consisting of three standard tandem pump units which can be switched on and off as required. The series connection of the pump units is permitted because one unit is capable of providing the full amount of torque for both rotors within its speed range. The torque/speed curve of a pump unit is shown in Figure 15.

The pumps are switched on and off automatically based on the requirements of a mixing process learnt by the system. Thus, there is a learning mode in which all the units are employed. The drive system control saves the process data for this mix and will automatically switch parts of the plant on and off as required when the mixing cycle is repeated in series mode. This means that when the mixer is operating with a partial load, as is often the case, the power loss from the drive is reduced considerably because of the lower effective drive power.

Now, if one of these pump units is additionally combined with a frequency converter, the torque/speed curve illustrated in Figure 16 is obtained. The use of a frequency converter can extend the speed range of a pump considerably. In many cases, however, the reduced torque in this range should be sufficient, e.g. to allow laminar mixing of the curing system.

The multi-layer principle shown here by way of example offers considerable advantages, particularly for retrofitting. The modular construction using tried and tested components results in reduced procurement and commissioning costs. By analysing existing process data from the mixing process, the layers can be...
individually allocated to meet the requirement profile of the plant being designed. For instance, multi-layers with individually selected pump sizes and drives are a very promising option.

CONCLUSIONS

Although the tangential mixing principle has been known for many years, it still offers a great deal of unexploited potential. Intelligent drive technology offers advantages in terms of process engineering and can be retrofitted to existing plants at reasonable cost. The level of increase in efficiency depends on the rotor geometry being used and should be re-examined for different rotor designs.

Modern multi-layer drives offer supplementary ways of improving the economic efficiency of the mixing process by means of energy savings. In particular, a prior analysis of existing process data makes it possible to design highly efficient drive technology. Since standard equipment can be meaningfully combined in multi-layer designs, suitable data is available for various operating points of these components so that, based on the existing process data, the potential energy saving can be simulated/estimated before making an investment.

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