Comparative analysis of screw drive modes in rubber double-cone twin-screw extrusion calender

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Abstract: The rubber double-cone twin-screw extrusion calender is a key high-efficiency mixing and molding equipment in the modern rubber industry. The performance of its transmission system directly affects the stability, energy consumption, and product quality of the equipment.This paper analyzes two mainstream transmission modes of the screw driven by a single motor: the single reducer + synchronous bevel gear linkage mode and the dual reducer + universal joint coupling in series mode. A systematic comparison is conducted from the perspectives of working principle, structural characteristics, performance, energy efficiency, maintenance cost, and applicable scenarios, revealing their core advantages and disadvantages. The research shows that the former has significant advantages in high synchronization accuracy, compact structure, high transmission efficiency, and simple maintenance; the latter has notable advantages in reasonable load distribution, strong power expansion, high operational reliability, convenient maintenance, and wide process adaptability. The conclusions of this paper provide an important theoretical basis for equipment selection and optimal design.

Key words: twin-screw extruder; transmission system; synchronous bevel gear; universal joint; comparative analysis

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0 Introduction

The rubber double-cone twin-screw extrusion calender is a core downstream equipment in the rubber industry, primarily used in conjunction with a mixer. It is responsible for processing the rubber compound after mixing through forced conveying, extrusion, cooling, and other processes to produce uniform sheets. It is widely used in the production of rubber products such as tires, seals, and conveyor belts. The core of this equipment lies in the fact that the screws are usually conical (with the diameter decreasing from the feed end to the discharge end), intermeshing and rotating synchronously in opposite directions, forming a "C-shaped chamber" structure to achieve forced advancement of the rubber compound and prevent material slipping or stagnation. At the same time, the centerline of the obliquely installed screws forms a certain angle (such as 15°~25°) with the horizontal, utilizing the component of gravity to reduce axial bearing loads, extend lifespan, and enhance conveying efficiency. Currently, there are two typical technical paths for achieving synchronous rotation of the two screws: one is to drive a single reducer with a single motor, then connect the reducer in series with a long screw, and install synchronous bevel gears on the two screws to achieve synchronous rotation; the other is to directly connect a single motor with a reducer, and then connect the two reducers in series through a universal joint shaft for joint operation, with each reducer driving one of the two screws to rotate. These two driving methods have their own characteristics in terms of structural design, transmission efficiency, and maintenance costs, directly affecting the performance and economic benefits of the equipment.

Biography: Kang Pengzhi (1989-), bachelor's degree holder, engineer, primarily engaged in the design and research and development of rubber mixing equipment.

1 Analysis of the linkage mode of single reducer + synchronous bevel gear

1.1 Structural features and operating principle

1.1.1 Core composition

Single motor, single high-power/high-torque main reducer, one through main drive screw, one set of high-precision synchronous helical bevel gear pair, driven screw (see Figure 1).

1.1.2 Power transmission path

Motor → main reducer → main screw → synchronous bevel gear pair → driven screw.

1.1.3 Synchronization mechanism

It relies entirely on the precise meshing of the bevel gear pair installed at specific positions on the two screws to forcibly achieve instantaneous angular velocity synchronization between the two screws.

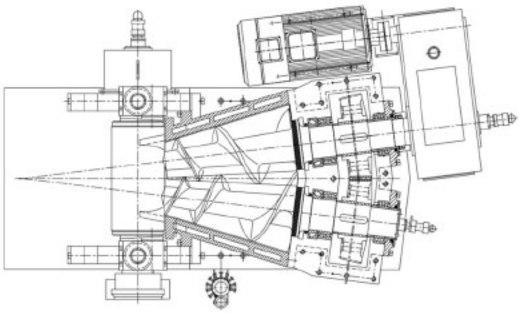

Figure 1 Single reducer + synchronous bevel gear linkage mode

1.2 Technical advantages

1.2.1 The structure is relatively simple and compact

Only one unit of main reducer is required, eliminating the need for additional reducers and longer intermediate transmission shaft systems. The overall structural layout is relatively simple and occupies less space.

1.2.2 Low initial investment cost

The procurement cost of one unit of large reducer has been reduced, and the related basic installation and alignment requirements have been simplified accordingly, resulting in a relatively low overall equipment manufacturing cost.

1.2.3 No intermediate transmission loss (theoretical)

The power transmission from the driving screw to the driven screw is directly accomplished through gear meshing, theoretically eliminating the efficiency loss incurred by intermediate components such as couplings (although gears themselves suffer from meshing losses).

1.2.4 Mechanical synchronization reliability (design ideal state)

Under the ideal condition of extremely high gear machining and installation precision, as well as absolutely balanced load, the meshing of bevel gears can provide rigid synchronization guarantee.

1.3 Analysis of limitations

1.3.1 Risk of uneven torque distribution

In the single reducer drive system, the torque of the two screws is entirely dependent on the distribution of the bevel gear pair. When there is an imbalance in the load on the two screws (such as uneven feeding or differences in rubber compound viscosity), it is easy for the bevel gear to bear additional radial force, which may affect the gear life in long-term operation. In severe cases, the phenomenon of "torque snatching" may even occur, where the screw on the side with lighter load speeds up, while the screw on the side with heavier load slows down, disrupting synchronicity.

1.3.2 The gear bears all the synchronous torque, resulting in stress concentration

The bevel gear pair not only transmits the torque required to drive the screw, but more importantly, it bears the huge "constraint torque" that forces the two screws to maintain synchronization. This makes the gear tooth root bear extremely high alternating bending stress and contact stress. The consequences: the requirements for gear material strength, heat treatment process, and manufacturing accuracy (especially tooth profile and tooth trace accuracy) are extremely stringent. Under heavy loads, impact loads, or poor lubrication conditions, pitting, spalling, and even tooth fracture failures are prone to occur on the tooth surface, making it a weak link and main failure point in the system.

1.3.3 The installation requires extremely high alignment precision

The bending of the screw, thermal expansion due to temperature rise, bearing clearance, and manufacturing errors of the gearbox itself all affect the meshing quality of the bevel gear pair (such as tooth side clearance and contact pattern). Ensuring precise alignment (spatial stagger angle and center distance) of the bevel gear installation position on the axis of the two screws under dynamic working conditions is very difficult and costly. The consequences: poor alignment can significantly exacerbate gear wear, noise, and vibration, reducing transmission efficiency and service life.

1.3.4 Maintenance difficulties

The gear pair is usually located inside the extruder barrel or in the sealed cavity at the end, facing harsh working conditions (high temperature, potential medium contamination). Once the gears are worn or damaged, maintenance or replacement often requires dismantling the screw or even part of the barrel, resulting in long downtime and high maintenance costs. Limited overload capacity: In severe overload or jamming situations, the huge impact load first acts on the fragile bevel gear pair, easily causing it to break. The system lacks an effective overload protection mechanism.

2 Analysis of the series connection method of dual reducers + universal couplings

2.1 Structural features and operating principle

2.1.1 Core composition

A single motor, two reducers of the same or similar specifications (main reducer, auxiliary reducer), a universal joint coupling (usually of the cross-shaft type), and two independently driven screws (see Figure 2).

2.1.2 Power transmission path

Motor → Main reducer → Universal coupling → Auxiliary reducer → Auxiliary screw. Meanwhile, the main reducer directly drives the main screw.

2.1.3 Synchronization mechanism

The synchronous rotation of two screws relies on the synchronization of the input speeds of two units of reducers. Since the motor drives the input shaft of the main reducer, which in turn drives the input shaft of the auxiliary reducer through a rigid or quasi-rigid universal joint, as long as the joint itself does not slip, the input shaft speeds of the two reducers are theoretically guaranteed to be instantaneously consistent. After passing through two reducers with the same reduction ratio, the output shaft (i.e., the screw) speeds naturally synchronize. The universal joint mainly addresses minor angular and positional deviations that exist during installation.

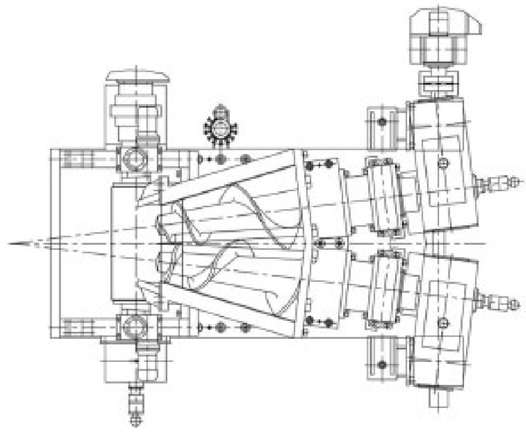

Figure 2 Series connection of dual reducers + universal joint

2.2 Technical advantages

2.2.1 Reasonable load distribution

A notable advantage of the dual-reducer system is its ability to achieve independent driving and load distribution for two screws. Each reducer is solely responsible for the power transmission of one screw, effectively eliminating the issue of uneven torque distribution found in single-reducer systems. When there is a load difference between the screws on both sides, the system can automatically adjust the torque distribution through the flexible connection of the universal joint, ensuring smooth operation.

2.2.2 Strong power scalability

For rubber extrusion applications with high power demands, the dual-reducer system possesses inherent advantages for expansion. By distributing the total load across two reducers, the design torque and dimensions of each reducer can be kept within reasonable limits, circumventing issues such as excessive size and processing difficulties encountered by single reducers in ultra-high power applications. In practical use, this system can effortlessly accommodate power ranges from tens of kilowatts to hundreds of kilowatts.

2.2.3 High operational reliability

The introduction of universal couplings has significantly enhanced the system's tolerance to installation errors and operational deformations. During the rubber extrusion process, factors such as thermal expansion of the screw and barrel, and foundation settlement may lead to changes in the relative position of the transmission axis. Universal couplings can effectively compensate for these deviations, ensuring the continuity and stability of the transmission.

2.2.4 Maintenance convenience

The modular design of the dual reducer system offers significant advantages in maintenance. The reducers can be independently serviced or replaced, eliminating the need for complete disassembly as required in single reducer systems. The universal joint coupling itself is also designed with standardization in mind, making it easy to replace worn parts. This design significantly reduces equipment maintenance downtime, which is particularly important for rubber enterprises engaged in continuous production.

2.2.5 The requirements for installation alignment are relatively lenient

Universal couplings, especially those with dual-unit or expansion joint structures, are capable of compensating for significant axial, radial, and angular installation deviations between reducers. This significantly reduces the precision requirements and difficulty of equipment manufacturing and on-site installation.

2.2.6 Modular design

Maintenance is relatively convenient. Both reducers have the same structure and are interchangeable. The universal joint is a standard component. If a single reducer or joint fails, it can usually be replaced by simply dismantling the faulty unit, without the need for extensive disassembly of the screw and cylinder, greatly reducing maintenance time.

2.3 Analysis of limitations

2.3.1 System efficiency is slightly low

Compared to a single reducer system, the dual reducer scheme adds an additional power transmission link (universal joint coupling and a second reducer) in the transmission chain, resulting in a decrease in overall transmission efficiency. Actual measurement data shows that the comprehensive efficiency of the dual reducer system is typically 2-5% lower than that of the single reducer system, which can accumulate considerable additional energy consumption during long-term continuous operation.

2.3.2 High initial investment

The dual-reducer system requires the configuration of two reducers and corresponding universal joint couplings, resulting in significantly higher equipment acquisition costs compared to the single-reducer solution. Additionally, the system imposes higher requirements on the synchronization accuracy of the reducers and the control system, further increasing initial investment. According to statistics, under the same power level, the procurement cost of the dual-reducer system is typically 20% to 30% higher than that of the single-reducer system.

2.3.3 Large space occupation

The side-by-side arrangement of two reducers requires more installation space, resulting in an increase in the overall length of the equipment. For rubber enterprises with limited space in their factories, this may become a limiting factor. In addition, the enlarged transmission system also brings complexity to the foundation construction, requiring stronger foundation support and more precise installation adjustments.

2.3.4 Increased maintenance complexity

Although the modular design of the dual-reducer system facilitates local maintenance, the number of maintenance points in the system has actually increased. Both reducers require regular inspection of the lubrication status and gear wear, and the universal joint coupling also needs attention to the wear and lubrication of its joint parts. This, to some extent, increases the workload and professional requirements of daily maintenance.

2.3.5 Vibration control challenges

The dual-reducer system may face more complex vibration issues during high-speed operation. There may be differences in the vibration characteristics of the two reducers, and the dynamic imbalance of the universal joint coupling may also introduce additional vibration sources. These issues need to be addressed through precise dynamic balancing correction and high-quality vibration reduction measures, increasing technical difficulty and cost.

3 Comparison of key performance indicators

3.1 Comparison of energy consumption efficiency

Energy consumption efficiency is one of the key indicators for evaluating the quality of the drive system of a rubber double-cone twin-screw extrusion calender, directly affecting the long-term operating costs of the equipment. Through in-depth analysis of two drive modes, it can be found that they exhibit significant differences in energy utilization efficiency. The single-motor single-reducer synchronous bevel gear drive system has a simpler transmission chain, with only one reduction and one bevel gear distribution from the motor to the screw, resulting in fewer energy loss links and relatively higher overall efficiency. The double-reducer universal joint drive system has relatively lower overall efficiency due to the addition of extra power transmission links. Although the efficiency gap can be narrowed by using high-efficiency reducers and precision universal joints, it cannot fundamentally change the energy loss caused by multi-stage transmission.

It is worth noting that the efficiency difference between the two systems varies with changes in load rate. Under full-load conditions, the efficiency advantage of the single-reducer system is most pronounced. However, under partial-load conditions, the dual-reducer system, which can adjust the load distribution between the two reducers, experiences a relatively smooth decrease in efficiency, narrowing the efficiency gap between the two systems.

From the perspective of energy consumption management, the single-reducer system is more suitable for applications with stable loads and continuous operation, such as the production of rubber products with large quantities and a single formula; whereas the dual-reducer system is more suitable for diversified production scenarios with large load fluctuations and frequent adjustments. When selecting a drive system, rubber enterprises should fully consider their own production characteristics and energy consumption structure to make a reasonable choice.

3.2 Comparison of maintenance costs

Equipment maintenance costs are a significant factor affecting the production efficiency of rubber enterprises. There are notable differences between the two drive systems in terms of maintenance frequency, difficulty, and cost.

The maintenance work for the single-motor and single-reducer synchronous bevel gear drive system primarily focuses on the reducer and the bevel gear pair. The reducer requires regular lubricant replacement (usually every 4,000 to 6,000 working hours) and inspection of gear and bearing wear. For the bevel gear pair, attention should be paid to the meshing clearance and lubrication status, with a comprehensive inspection and adjustment typically carried out every six months. The advantage of this system lies in its centralized maintenance points, relatively standardized maintenance procedures, and ease of mastery for factory maintenance personnel. The main maintenance costs include lubricant expenses and regularly replaced consumable parts such as seals, with an average annual maintenance cost accounting for approximately 1% to 1.5% of the equipment value.

The maintenance of the dual-reducer universal joint drive system is more complex. In addition to the routine maintenance of each of the two reducers, the universal joint is a component that requires special attention. The cross shaft, bearings, and splines of the joint need to be lubricated regularly (usually every 500 working hours) and inspected for wear. At the same time, due to the presence of multiple connections and alignment links in the system, more frequent alignment inspections (recommended every three months) are necessary to prevent vibration and wear caused by misalignment. The annual maintenance cost of such a system is usually high, accounting for about 1.8% to 2.5% of the equipment value, and it requires higher professional skills from maintenance personnel.

From a long-term operational perspective, the key components of a single reducer system (especially the bevel gear pair) often require professional repair or replacement after multiple maintenance procedures, and the cost of such major overhauls is relatively high. Although the dual reducer system requires frequent routine maintenance, due to a more balanced load distribution, the service life of its key components is typically longer, and the overhaul cycle is relatively postponed. Statistical data indicates that the total maintenance cost difference between the two drive systems over a 10-year usage period is usually within 15%, with the specific advantages and disadvantages depending on actual usage conditions and maintenance levels.

For small and medium-sized rubber enterprises with limited maintenance resources, a single reducer system may be more suitable due to its simple maintenance and long cycle; while for large enterprises with professional maintenance teams, the modular design and redundancy of a dual reducer system can provide higher operational guarantees.

3.3 Comparison of service life

The service life of equipment is a crucial factor for rubber enterprises to consider when making investment decisions, and the two drive systems differ in terms of the durability and overall lifespan of their key components.

The lifespan bottleneck of a single-motor, single-reducer synchronous bevel gear drive system is typically concentrated on the bevel gear pair. Under high-torque, continuous operating conditions, tooth surface contact fatigue and wear are the primary failure modes of the bevel gears. Bevel gears made of high-quality alloy steel and subjected to carburizing and quenching treatment can generally operate for 60,000 to 100,000 hours under normal maintenance conditions. The reducer itself typically has a longer lifespan, reaching over 100,000 hours. The overall lifespan of the system largely depends on the maintenance and replacement of the bevel gears. With proper use, the entire transmission system can serve for over 15 years.

The lifespan characteristics of the dual-reducer universal joint drive system are more complex. The lifespan of both reducers is comparable to that of a single reducer system, both reaching over 100,000 hours. The lifespan of the universal joint is typically between 30,000 to 50,000 hours, requiring regular replacement of key components. The overall lifespan of the system is limited by the weakest link, but thanks to the modular design, the overall service life can be extended through local replacement. In practical applications, the full life cycle of such a system can reach 12 to 15 years, slightly lower than that of a single reducer system, but it can be further extended through reasonable component updates.

It is worth noting that the lifespan performance of the two systems is closely related to the load conditions. Under stable full-load conditions, the single reducer system exhibits a more pronounced lifespan advantage; whereas under variable loads and frequent start-stop conditions, the dual reducer system demonstrates better adaptability and slower lifespan degradation. Rubber enterprises should assess which system better meets their long-term usage requirements based on their specific production characteristics.

From the perspective of technological development, with advancements in material science and manufacturing technology, the lifespan of both systems is continuously improving. The application of new high-strength alloys, surface treatment technologies, and condition monitoring systems has increased the service life of modern rubber double-cone twin-screw extrusion tablet presses by 30% to 50% compared to ten years ago, which has narrowed the gap in lifespan between the two systems to some extent.

4 Conclusion

The two drive configuration schemes for rubber double-cone twin-screw extrusion tablet presses each have their own characteristics, and there is no absolute superiority or inferiority between them. The single motor-single reducer-synchronous bevel gear system has a simple structure, low cost, and high synchronization accuracy, making it suitable for small and medium-sized equipment; the single motor-double reducers-universal joint system has strong load capacity and good flexibility, making it suitable for large high-load equipment. When selecting equipment, factors such as production needs, load characteristics, budget constraints, and technical support capabilities should be comprehensively considered to choose the most suitable drive configuration scheme.