Latest developments in radial forging technology for titanium and nickel alloys

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Radial forging is a pivotal incremental forming process for manufacturing high-performance components with superior mechanical properties, particularly for aerospace applications and semi-finished products in medical engineering, energy technology and railway industry. Due to narrow processing temperature windows, strain-rate sensitivity, and stringent requirements regarding microstructural integrity, titanium and nickel-based alloys pose significant challenges to process management. To enhance process efficiency, ensure reproducible quality, and reduce energy consumption, this paper presents the latest developments by SMS group in the fields of automation, process technology, and machine drive concepts. Particular focus is placed on a novel forging strategy ("2+2 forging") as well as an energy-efficient drive concept for hydraulic radial forging machines.

KEYWORDS: RADIAL FORGING, ENERGY EFFICIENCY, DRIVE CONCEPT, FORGING STRATEGIES

CURRENT CHALLENGES IN RADIAL FORGING

The current challenges in radial forging can be categorized into four primary areas of action:

- First, process reproducibility requires precise control to ensure consistent component quality and homogeneous properties.
- Second, the shortage of skilled labor intensifies the need to reduce operator dependency and design highly automated, robust operations.
- Third, energy efficiency must be improved to mitigate rising energy costs and reduce the carbon footprint through lower energy consumption and reduced connected electrical loads.
- Fourth, the requirements for material properties continue to increase, necessitating innovative forging techniques to achieve microstructural homogeneity, fine grain size, and exceptional material performance in titanium and nickel-based alloys.

To address these challenges, SMS group has developed an automated forging line alongside a new, energy-efficient drive concept for hydraulic forging presses and radial forging machines. In combination with advanced forging strategies, this system achieves superior material properties resulting in improved grain size, which were validated with several forging trials.

Automated Forging Line

The production of components from nickel-based and titanium alloys requires precise process control because these materials demand carefully managed forging operations to achieve the intended mechanical properties and microstructures. In a typical integrated forging line, an open-die forging press and a radial forging machine are coordinated with furnaces and material-handling systems, however the planning and handling operation requires several manual steps impeding process stability and reliability. The line concept developed by SMS group integrates machine operation, material handling, and tracking between furnaces, open-die presses, and radial forging machines, thereby reducing manual intervention and supporting reproducible production conditions.

The automated line control covers forged products requiring high automation and production capacity. It integrates tracking and process coordination from the furnace to the open-die press and further to the radial forging machine. From an engineering perspective, this arrangement supports a consistent process chain in which transport times, forging sequences, and machine states can be coordinated in a documented manner. This is particularly relevant for critical alloys with narrow processing windows, where delayed transfer or inconsistent process execution can affect the temperature and deformation history of the workpiece.

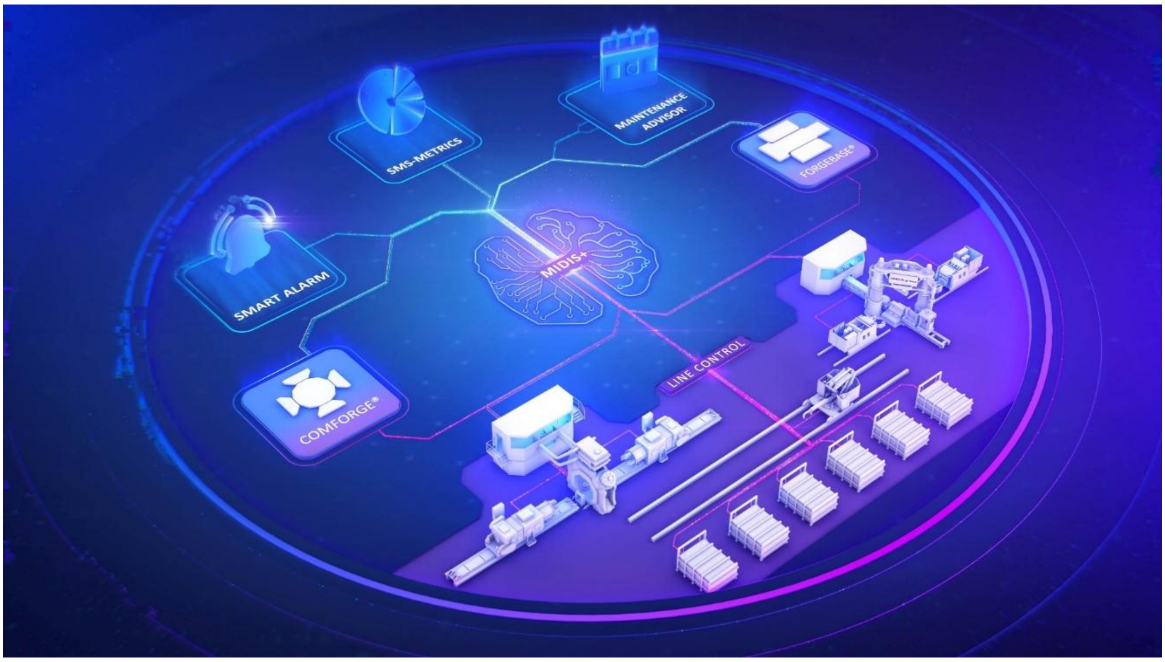

Figure 1: Concept of automatic line control

SMS group supplies complete forging lines from a single source, including high-speed open-die forging presses, SMX hydraulic radial forging machines and an integrated production control system.

New Drive Concept for hydraulic radial forging machines to improve energy efficiency

The new drive concept is based on the continued development of hydraulic drive systems for SMX radial forging machines. Conventional hydraulic concepts may use stand-alone arrangements of hydraulic components, single pumps driven by individual asynchronous motors, and hydraulic rooms with extensive piping. In contrast, the optimized hydraulic concept consolidates essential hydraulic components into a compact, pre-assembled unit. This compact drive is installed as a complete entity and is reported to reduce installation effort, simplify commissioning, and improve accessibility for maintenance.

For SMX radial forging machines, the hydraulic drive concept has been developed stepwise: eco mode with swiveling pumps during idle time, elimination of the boost system through the compact drive system, operation with frequency converters and synchronous reluctance motors, and flywheel technology for reduced motor power requirements.

In the development sequence, the compact drive step reduces installed power by 9% and energy consumption by 22%; the frequency-converter and motor step is associated with reductions of 15% and 23%; and flywheel technology is associated with reductions of 50% in installed power and 25% in energy consumption relative to the indicated reference basis.

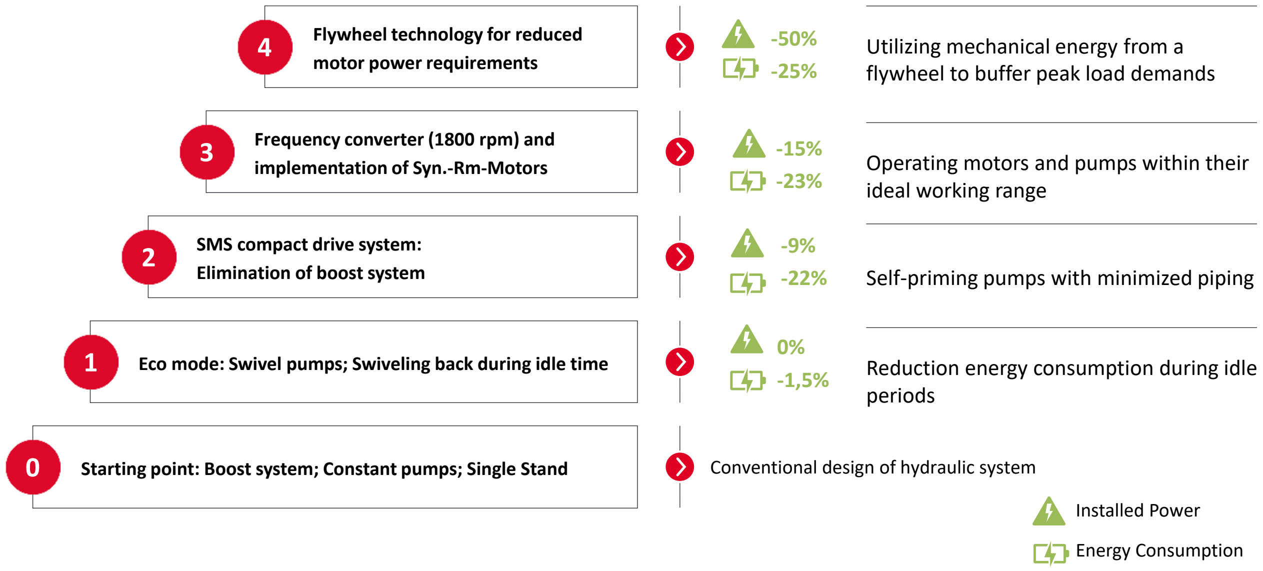

Figure 2: Evolution steps in SMX drive concept

The flywheel is used as a mechanical energy buffer integrated into the motor-pump arrangement. During the deformation phase, the pump rotational speed can decrease by approximately 60 rpm, corresponding to about 3.3%, so that energy is supplied from the flywheel while the electrical motor continues to operate close to its best efficiency range. This behavior has no noticeable effect on forging performance.

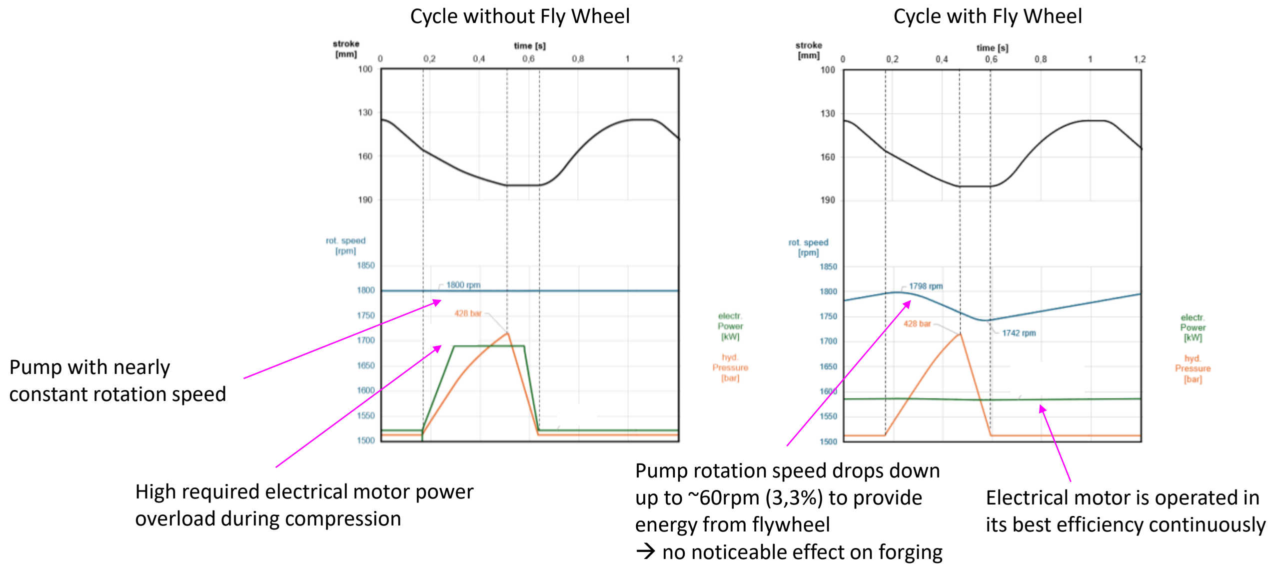

Figure 3: Forging cycle with and without Flywheel

In an SMX 22 MN example, the latest 2025 design is compared with a 2012 reference: total installed power decreases from 10,600 kW to 5,600 kW, and total peak power decreases from 16,000 kW to 7,500 kW. The same comparison reports reductions of 47% in installed power, 53% in peak power, 50% in space requirement, and 50% in hydraulic piping.

The advantages of hydraulic drive technology are not limited to energy and installation aspects. Hydraulic radial forging machines provide flexible control of velocity, position, and force, while the full forging force is available over the entire stroke of each forging cylinder. This characteristic allows controlled penetration speed and controlled material deformation, which is important for titanium and nickel-based alloys. Inappropriate deformation speed can negatively affect grain structure in titanium, whereas the hydraulic drive enables precise control needed to reduce the risk of surface cracks and support homogeneous temperature and deformation conditions.

2+2 Forging: Advanced radial forging with superior material properties

Common forging strategies mainly cover spiral forging. Here, the workpiece is rotated after every stroke leading to a spiral rotation of the forging dies around the workpiece. Although this forging strategy allows for a high productivity, the achievable core penetration is limited since compared to open-die forging, only small manipulator drive steps can be realized.

The 2+2 forging strategy is an advanced SMX radial forging strategy enabled by the hydraulic drive. In conventional spiral forging, the manipulator advances and rotates with each stroke; this strategy is productive and capable of achieving good surface quality, but it represents a compromise between microstructural improvement and productivity. In linear, or RUMX, forging, the manipulator is not rotated after every stroke, and larger feed increments are used, increasing the hydrostatic stress component and improving core deformation and pore closure.

In the 2+2 strategy, the two die pairs are actuated alternately without workpiece rotation. The process sequence is described as a stroke of tool pair 1, feed, and a subsequent stroke of tool pair 2. The workpiece can spread freely during deformation by one die pair and is then forged by the second pair, producing an intermediate square-like cross-section that is subsequently rounded in the final planishing operation. For this reason, the strategy is characterized as “open-die forging on a radial forging machine.” The essential process logic is therefore the combination of radial forging productivity with deformation characteristics similar to open-die forging.

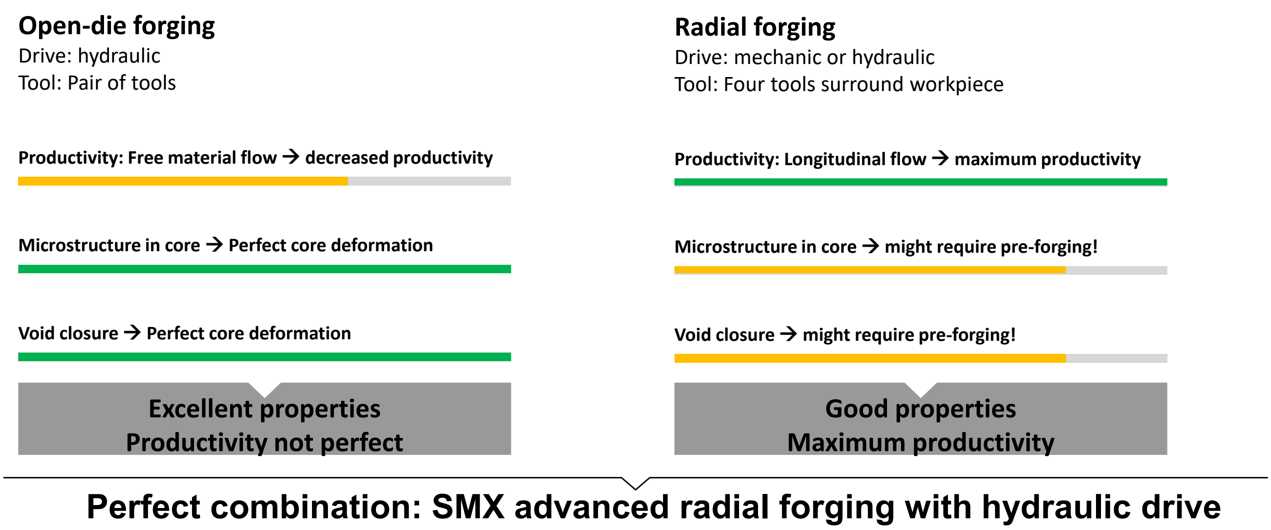

Figure 4: Comparison between Open-die forging and radial forging

Experimental testing of 2+2 forging was successfully performed on an SMX 18 MN machine for steel, titanium, and Ni-base materials, with a positive influence on microstructure observed. The customer benefit is summarized as better deformation of the core, better material properties, and possible elimination of pre-forging.

For validation, the following forging parameters were chosen:

- Forging of two ingots of Inconel 825
- Starting Temperature Heat 1: 1180 °C
- Starting Temperature Heat 2: 1110 °C
- Heat 1: Spiral forging
- Heat 2:
    - Ingot 1: Conventional spiral forging
    - Ingot 2: 2+2 Forging

The ingot was forged from an initial diameter of 570 mm to a final diameter of 200 mm.

During heat 1, high temperature forging was carried out to achieve reduction, while heat 2 at lower temperatures was used to achieve a fine grain size. The following pass-schedules were chosen for heat 2

Table 1: Pass-schedule comparison for heat 2

Ingot 1			Ingot 2		
Pass	**Forging height**	**Type**	**Pass**	**Forging height**	**Type**
1	310 mm	Spiral	1	316/309 mm	2+2
2	230 mm	Spiral	2	268/264 mm	2+2
3	205 mm	Spiral	3	230/223 mm	2+2
			4	205 mm	Spiral

Although the 2+2 forging sequence requires one forging pass more, the forging time increases only slightly by less than 30 seconds, since significantly larger manipulator steps can be achieved with 100 mm for 2+2 forging, while spiral forging allows only an avg. mani-drive step for 60 mm. This furthermore underlines, that 2+2 forging achieves similar manipulator steps as open-die forging.

After forging the grain size was evaluated by means of metallographic analysis in core, outer radius below surface and on half radius, see Table 2. The results impressively show that 2+2 forging allows for better core penetration and thus superior grain sizes and material properties.

Table 2: ASTM grain size for both forging sequences

Spiral forging		2+2 forging	
Surface	8	Surface	8
Half radius	6	Half radius	5
Core	1-4	Core	4.5

Summary.

This paper shows how SMS group advances radial forging for titanium and nickel-based alloys by combining automated line control, an energy-efficient SMX hydraulic drive concept, and the innovative 2+2 forging strategy. The result is a highly integrated process chain with reproducible quality, lower operator dependency, reduced installed and peak power, and improved material properties through enhanced core deformation and grain refinement. SMS thus provides not only forging equipment, but complete, efficient, and metallurgically optimized solutions for demanding aerospace and medical applications. **SMS radial forging technology enables efficient production of high-performance materials with reliable, reproducible excellence.**