Hyd. 2

Movable Roofs:
Conceptual design of the Stadium in Rome

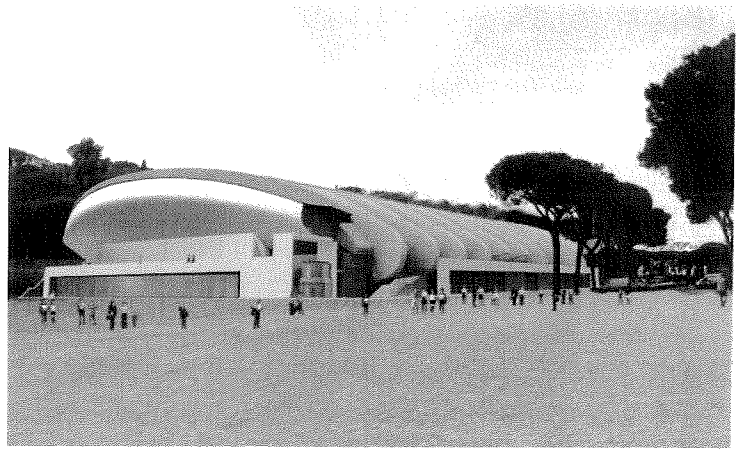
Introduction

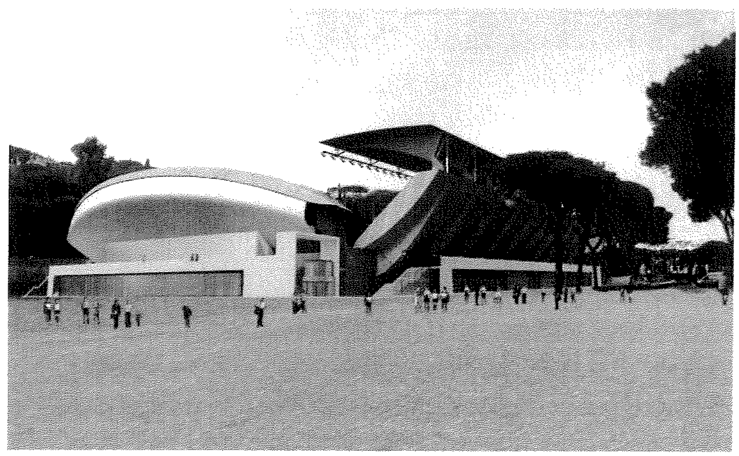
Modern multi-function sports location more often feature a roll-out pitch, a sliding roof and a movable stands. The experience of steel construction companies in structural steel engineering and crane technology, coupled with Rexroth's expertise in drive and control technology, makes it possible to provide solutions to these engineering challenges.

As sports stadia evolve, certain motivations arise to push the limits of technology for roof systems and to design a single structure which can create both indoor and outdoor environments tor multiple purposes.
When the majority of the professional sports stadiums were of the fully outdoor design, growing and maintaining a natural grass playing field was not considered difficult. With the advent of the large indoor domed professional sports stadium it has changed. Because of the lack of sunlight and natural precipitation, it has turned out being impractical to grow natural grass in a domed stadium. Roll-out pitches and kinetic structures to open the roof came into discussion.
Additionally there are serious financial motivations in considering building a retractable roof stadium: Although they incur considerable costs during construction, these functionality is important for securing revenue streams throughout the year. With the means of a movable roof a necessary step is taken to transform a sports stadium into a real multipurpose facility.
The success of the first generation of movable roofs in the beginning of the 90s led to a series of new projects at the end of the last century, most of them being build in the US, Korea or Australia. Five of the stadia being built in the US during that time feature a movable roof with the possibility to open the construction to up to 90 % clearance.
The designs of the various stadiums are quite different, but there are a number of features that seem to be common to all of the designs that have been implemented thus far. Most of the time, these structures are either winch driven, power by a Rack- and-Pinion Drive or moved into position by an arrangement of various hydraulic cylinders.

The forces created by the exertion of natural forces such as wind, rain snow and even earthquakes on such a large structure can be enormous, and the roof, the underlying stadium structure and the transport mechanism that is used to guide and move the roof between its retracted and operational positions must be engineered to withstand the worst possible confluence of such forces.
With today's advanced design and engineering capabilities, even complicated movable structures become realistic. One of these example would be the concept for the new tennis stadium in Rome

The concept of the Stadium in Rome

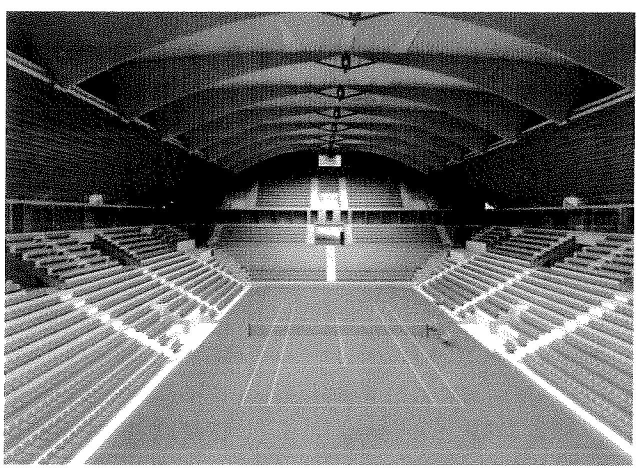




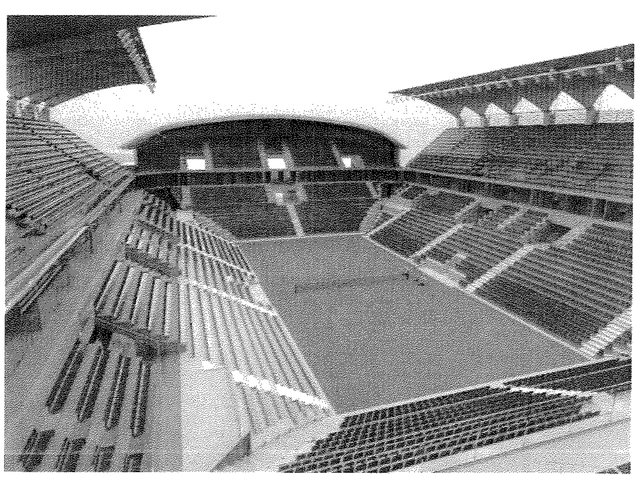
Initiated by the Olympic committee of Italy, the city of Rome has decided to replace the old, mostly wooden tennis court in the region Lazio in Rome by a new indoor/outdoor stadium for international tennis tournaments. The intention is, to use this completely new designed building also for different kinds of other sport- and public- events, like the foreseen `world of swimming 2009´. Also, other indoor sports and activities, like stadium Moto-cross or basketball can be organized within this multifunctional building, as well as concerts and other events.

The new building with a conventional concrete structure and numerous public areas in the lower section will be covered by a convertible steel- and aluminum shell construction for the upper section of the audience-seats and the roof. The stadium shall be incorporated in the original park-like green landscape right next to the already existing soccer stadium within the Olympic area with many old trees. Even though, the new construction with its extraordinary architectural design will be quite spectacular, it shall be not too dominating and rather integrate itself into the existing surrounding – even in the `open version´.

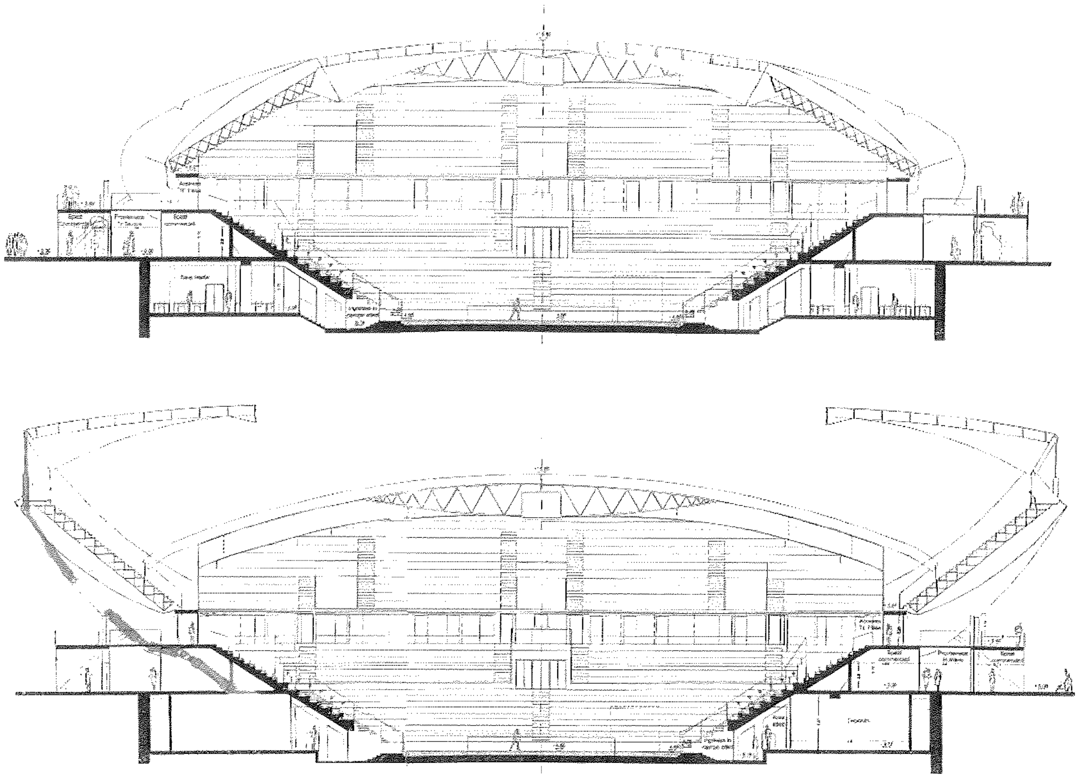
Interior view – roof closed



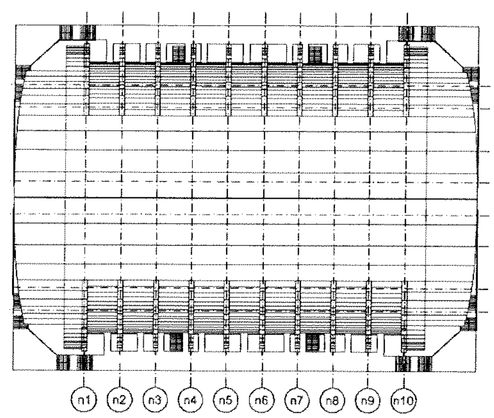
Interior view – roof opened, additional seating



The construction does foresee, that both longitudinal sides of the stadium-roof can be opened completely by an exceptional, hydraulic-driven mechanism and thus provide a significant number of additional seats in the `open´-mode. When switching from `closed´-mode to `open´- mode, they will gain some one thousand additional seats for spectators and thus increase the stadium-capacity by approximately 30%.
In the warm city of Rome it shall be possible to use the open version during most of the summer events. Closing the roof is only foreseen for winter-time and a longer lasting bad weather season. It will not close permanently and not just because of short rain-showers.



Each longitudinal side, consisting of 10 equal roof sections with about 7,5 m in width, is assembled out of two basic element structures. The lower (steel) segment with integrated seats for the `open´-mode and a separate, lighter top-roof (e.g. aluminum). Of course the mechanism will be locked and not used as long as spectators are present.

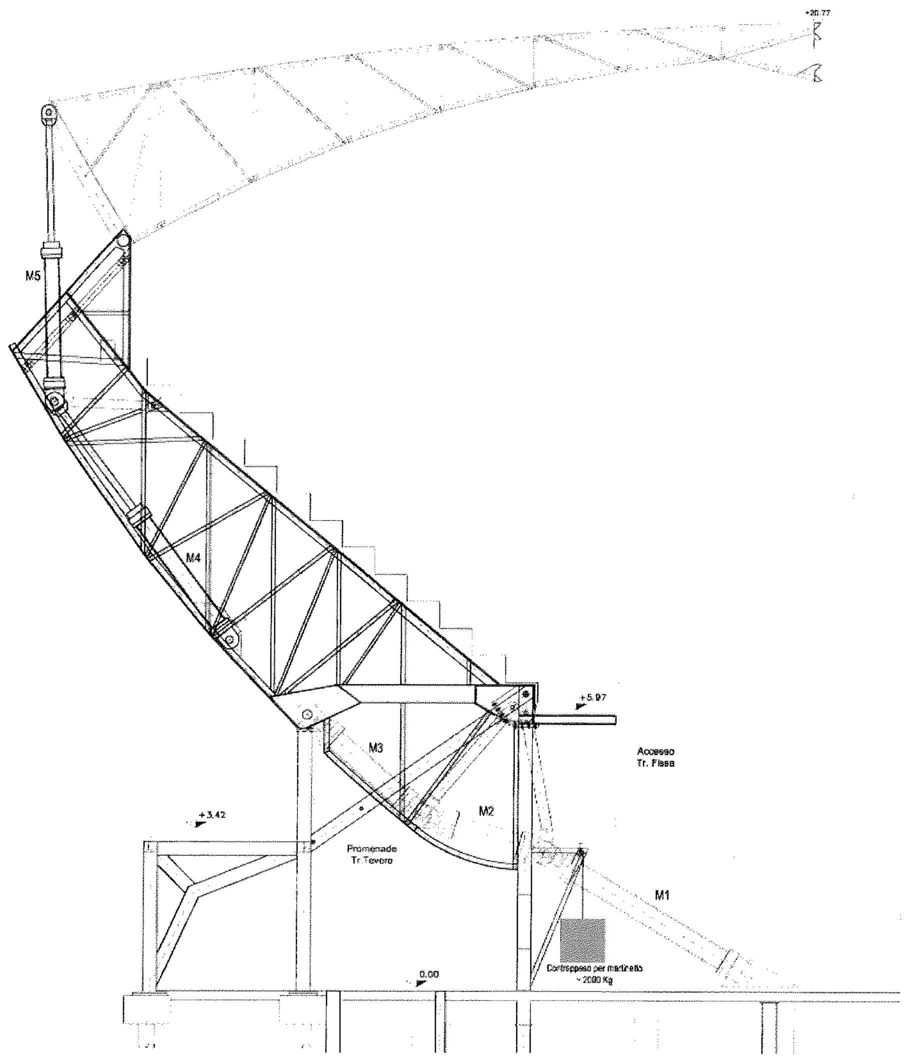


Above:
Section of stadium concept in closed and opened position (hydraulic cylinders marked in red)

Right:
Top view on stadium with 10 equal roof sections

The mechanical concept

To achieve this high flexible movement within the narrow designed outside-shell, and with very limited, available space for the driving mechanism, every section itself shall incorporate 5 different hydraulic cylinders.(M1 to M5)

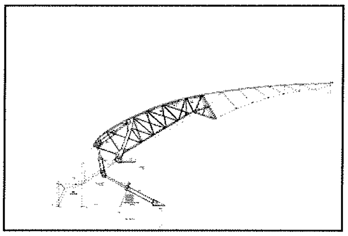


During opening and closing cycles, the interaction between the individual cylinders which work together at same time, will be optimized, to achieve a smooth synchronous movement and a most efficient sharing of the installed hydraulic capacities.
The total time for one operating cycle - as well for opening and for closing - is about 30 minutes.
The specified tolerance between identical cylinders from `neighbor´-sections during the operation is just a few Millimeters, to achieve the impression of a absolute parallel movement of all roof sections at a time and finally a minimum difference of the top-edge.

Cylinder configuration

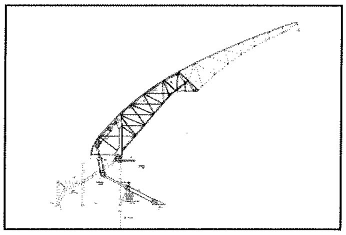
#	Cylinder bore [mm]	Cylinder rod [mm]	Cylinder stroke [mm]	Total qty.
M1	400	220	2822	20 pcs.
M2	400	180	1250	20 pcs.
M3	400	180	1712	20 pcs.
M4	320	140	2492	20 pcs.
M5	280	125	2449	20 pcs.

Opening sequence of roof



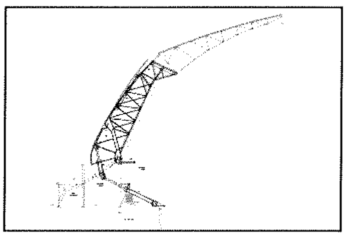
Fully closed position

	Cylinder position
M1	100%
M2	100%
M3	100%
M4	0%
M5	0%



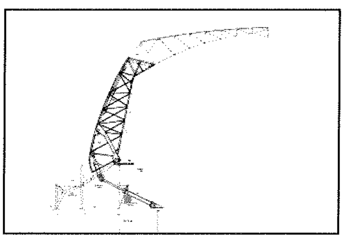
Phase 1

	Cylinder position
M1	100%
M2	100%
M3	from 100% to 50%
M4	0%
M5	0%



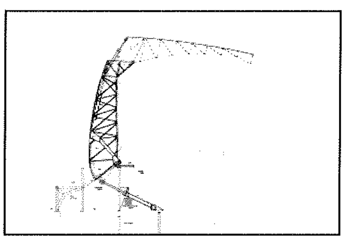
Phase 2

	Cylinder position
M1	100%
M2	100%
M3	from 50% to 0%
M4	from 0% to 50%
M5	0%



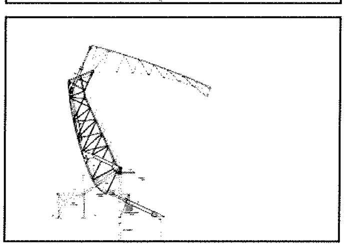
Phase 3

	Cylinder position
M1	100%
M2	from 100% to 50%
M3	0%
M4	from 50% to 100%
M5	0%



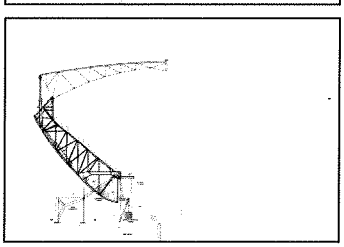
Phase 4

	Cylinder position
M1	100%
M2	from 50% to 0%
M3	0%
M4	100%
M5	from 0% to 50%



Phase 5

	Cylinder position
M1	from 100% to 50%
M2	0%
M3	0%
M4	100%
M5	from 50% to 100%

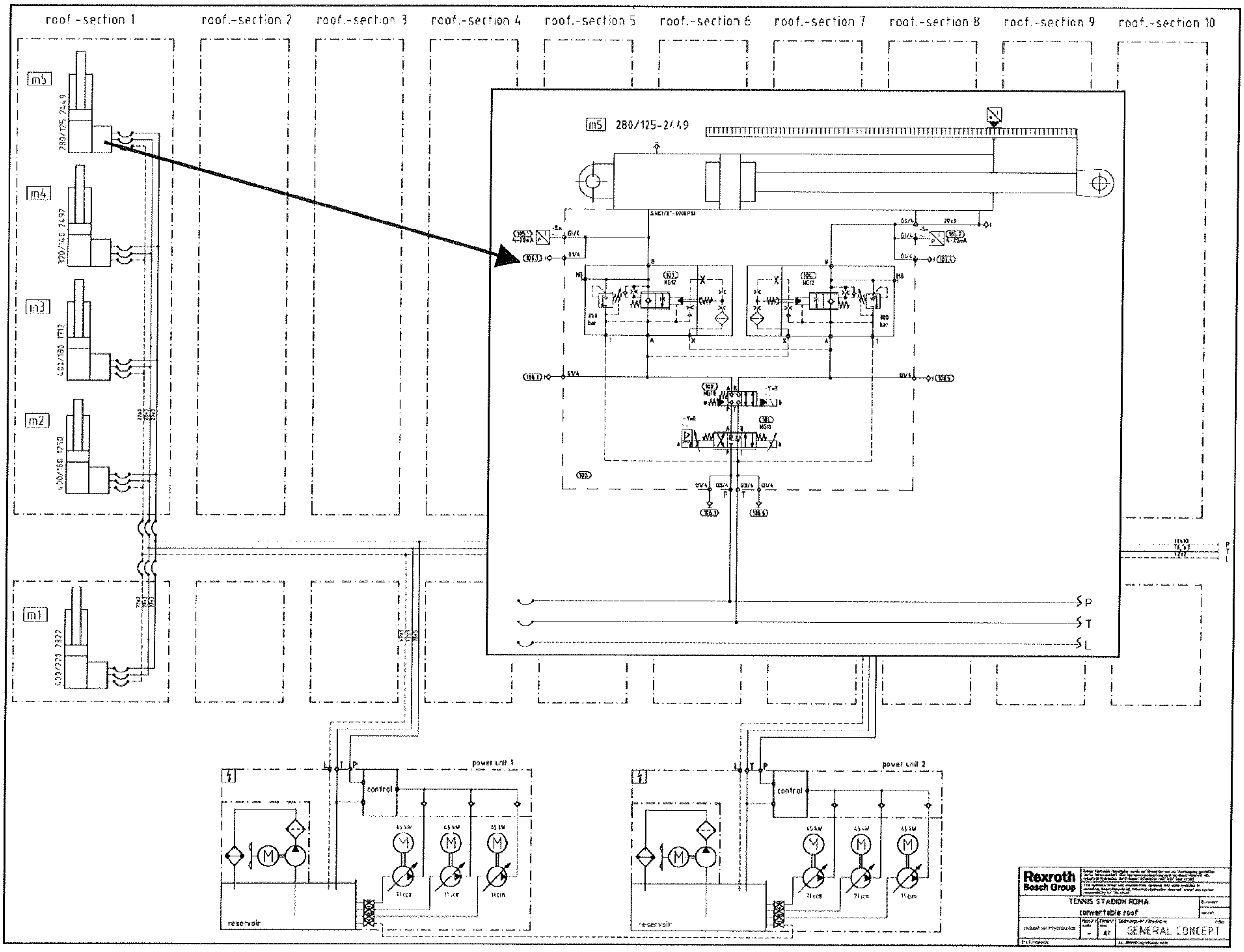


Fully open position

	Cylinder position
M1	from 50% to 0%
M2	0%
M3	0%
M4	100%
M5	100%

The hydraulic drive concept

Even though the power-units will be dimensioned big enough to guarantee sufficient oil-supply to all 100 cylinders which operate during such a movement, the hydraulic conception does foresee a very efficient, small system with one common the power unit / reservoir in the basement for the supply of all 50 cylinders for one roof side (10 identical sections, with 5 cylinders each).

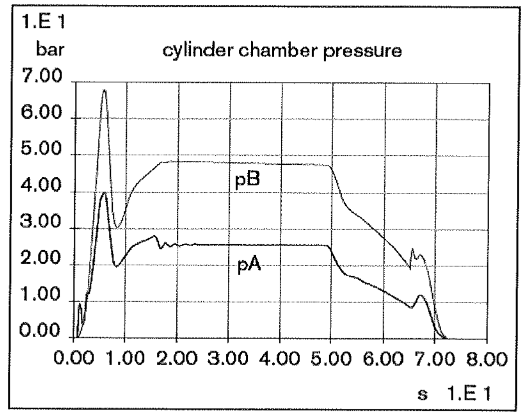


Every system for one longitudinal side must be able to operate ten roof sections at the same time, synchronously with high precision. During the closing- or opening- procedure of the roof, the movement of the individual sections must not exceed a certain tolerance between each other to achieve a simultaneous impression.

Each cylinder will be equipped with an individual, absolute position measuring device and a corresponding control for each to allow an individual, proportional movement of every axis. Every cylinder must have a proportional control for fine adjustable and smooth movement with ramp function for acceleration and deceleration.

The conception with individual safety-manifold with proportional control and individual, high-precision measuring device, in cooperation with a sophisticated electronic control program, will allow a very precise, synchronous movement of all roof sections with high accuracy.

Very similar to the design of movable bridges, where external disturbance variables such as wind loads could affect a structure or system, the vibration behavior of the whole system needs to be observed. With its own developed hydraulic computer simulation program MOHSIS, Rexroth is able to verify that the chosen hydraulic and electric system will be able to achieve the correct, safe function and synchronous movement of the roof sections. Occurring vibration levels may need to be kept within the limits of a non-critical tolerance range by implementing certain modifications based on these simulations.



The development of a suitable drive-solution for this project, the system-layout with correlating electric and electronic equipment, the appropriate program with a motion simulation and the supply of all required hardware from power-units to piping at site is a typical example for our `drive & control´ philosophy from Bosch-Rexroth.

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