MAGNETOM Free.Max: Keeping a Hot System Cool

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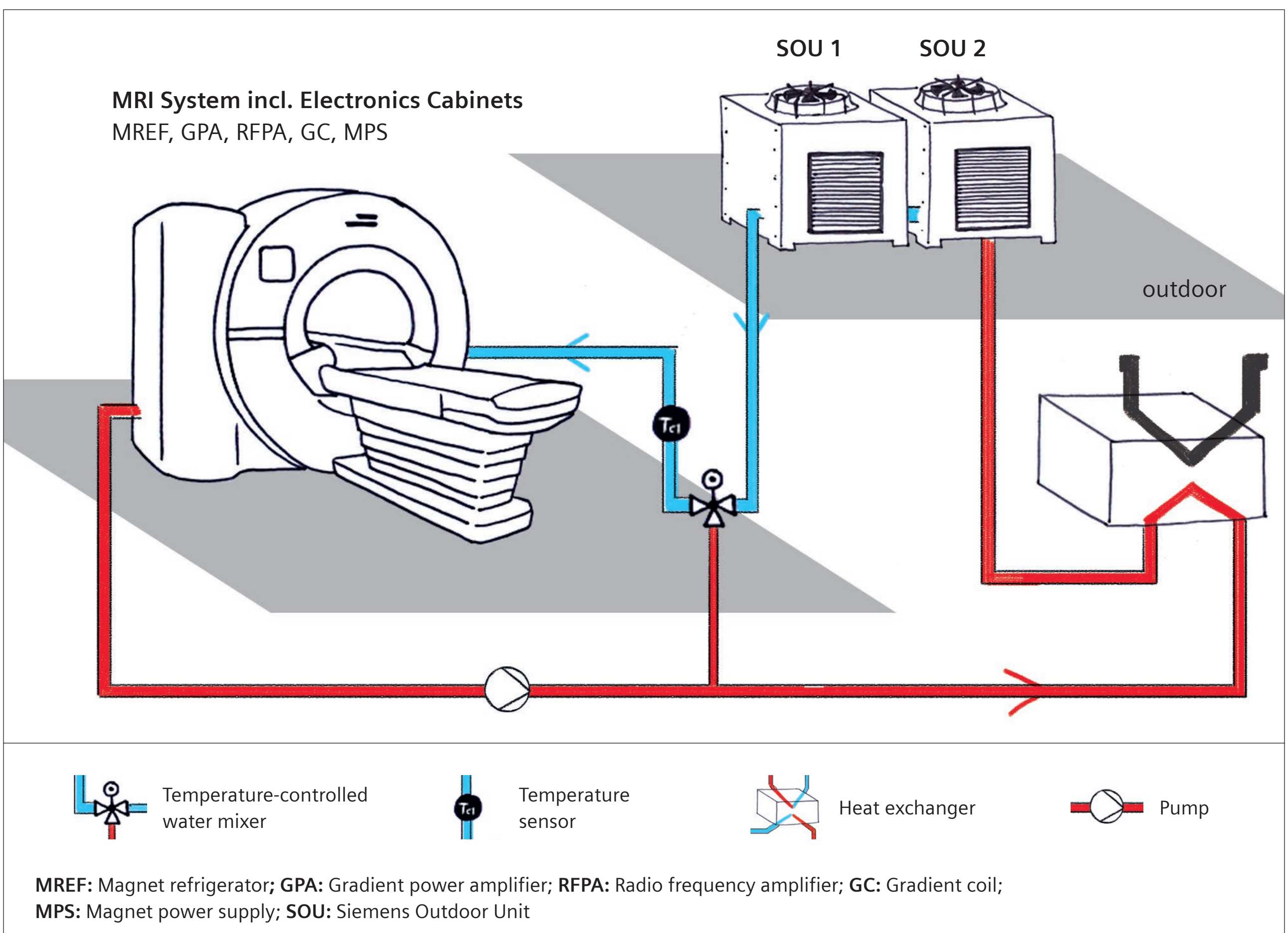
Helium is a rare element on Earth. Once released into the atmosphere, it is so lightweight that it leaves Earth's gravitational field and diffuses into space. DryCool technology, one of the key innovations on MAGNETOM Free.Max, reduces the helium demand in MR systems and removes the need to handle liquid helium during system installation. It also saves helium and prevents it from being released into the atmosphere during both normal system operation and failures such as quench events. However, the dramatic reduction of liquid helium to 0.7 liters contained in each MR magnet reduces the heat capacity of the magnet. If a conventional magnet loses cooling – e.g., due



1 Active cooling system with external chillers.

to a power outage or a failure of the cooling system – the liquid helium slowly starts evaporating. Once a certain pressure threshold is exceeded (usually after less than 1 hour), the magnet loses helium into the ambient atmosphere. Depending on the filling level, a conventional magnet can stay cold by continuously evaporating its helium reservoir for many days without losing superconductivity. This is because the helium reservoir contains several hundred liters of helium. Reducing the helium down to less than 1 liter for DryCool magnets therefore also reduces the tolerance of such systems against infrastructure failures. The main types of failure are power outages and failures of the cooling system. This paper describes how MAGNETOM Free.Max can provide high availability of the MRI scanner despite a liquid helium inventory of only 0.7 liters.

Power outages

Power outages are external events, out of control of the MRI system. The system can only react accordingly; it cannot avoid the situation itself. With DryCool technology, a small integrated uninterruptible power supply (UPS) keeps the magnet electronics running even during a power outage. If the power outage persists, the magnet electronics will ramp down the magnet after a certain waiting time in order to avoid a quench event, which would turn all the energy in the magnetic field into heat and warm up the system significantly. With MAGNETOM Free.Max, ramping the magnet down and then back up to field is now an automatic procedure which no longer requires an onsite visit from a service technician, due to the integrated magnet power supply. After a controlled ramp down, the magnet heats up very slowly. Once power returns, it can be recooled and ramped up again [1]. In regions where power reliability is poor, the system can also be buffered with a large UPS which not only keeps the system cold, but also enables continuous scanning even during brownouts or blackouts of the power grid.

Cooling system failures

Unlike power outages, the reliability of the cooling system is very much under the control of the MRI system design. For an imaging modality like MRI, which relies so much on cooling, the reliability of the cooling system is essential for guaranteeing high availability of the MRI system. The MAGNETOM Free.Max cooling system was developed with the need for high reliability in mind from the very beginning. The following section explains the redundancy-focused architectural measures which were applied to MAGNETOM Free.Max.

A liquid helium temperature of 4 K is achieved using a cryocooler ("cold head") which is driven by a compressor. The compressor (magnet refrigerator = MREF) requires approximately 6–8 kW of power to generate ~1 W cooling power on the 4 K level. In order to ensure permanent operation of the compressor, which keeps the magnet cold, the MREF must be supplied with electricity and cooling water. Cold water for MAGNETOM Free.Max can be provided by two different options:

Active cooling system

One option is to buy an external chiller which is tailored to operate with the MRI system. The flow diagram in Figure 1 shows that, in this case, the same water running through the MR components (MREF, gradient coil, amplifiers) is also running through the outdoor units SOU 1 and SOU 2. In such a configuration, the MRI system is self-contained and does not rely on any external water supply. This makes the setup very reliable because it avoids clogging of water flow or corrosion due to dirt and debris from external cooling water.

Chillers are located outside the building, often on rooftops or parking lots, where they use the ambient air to dissipate the heat from the MRI system. As they are located outdoors, chillers are exposed to all kinds of weather conditions: Temperatures can range from -20°C to +45°C, and dirt, dust, or leaves can block the heat exchangers. In highly reliable cooling systems, the outdoor units are a weak point in the chain. If an outdoor unit fails, the helium compressor will stop working and this will soon cause the magnet to ramp down. For the new DryCool technology, the chillers were designed with built-in redundancy to overcome this problem. During heavy-load scanning (mainly diffusion imaging) MAGNETOM Free.Max can

2 Active cooling system with two ~17 kW Siemens Outdoor Units (SOU).

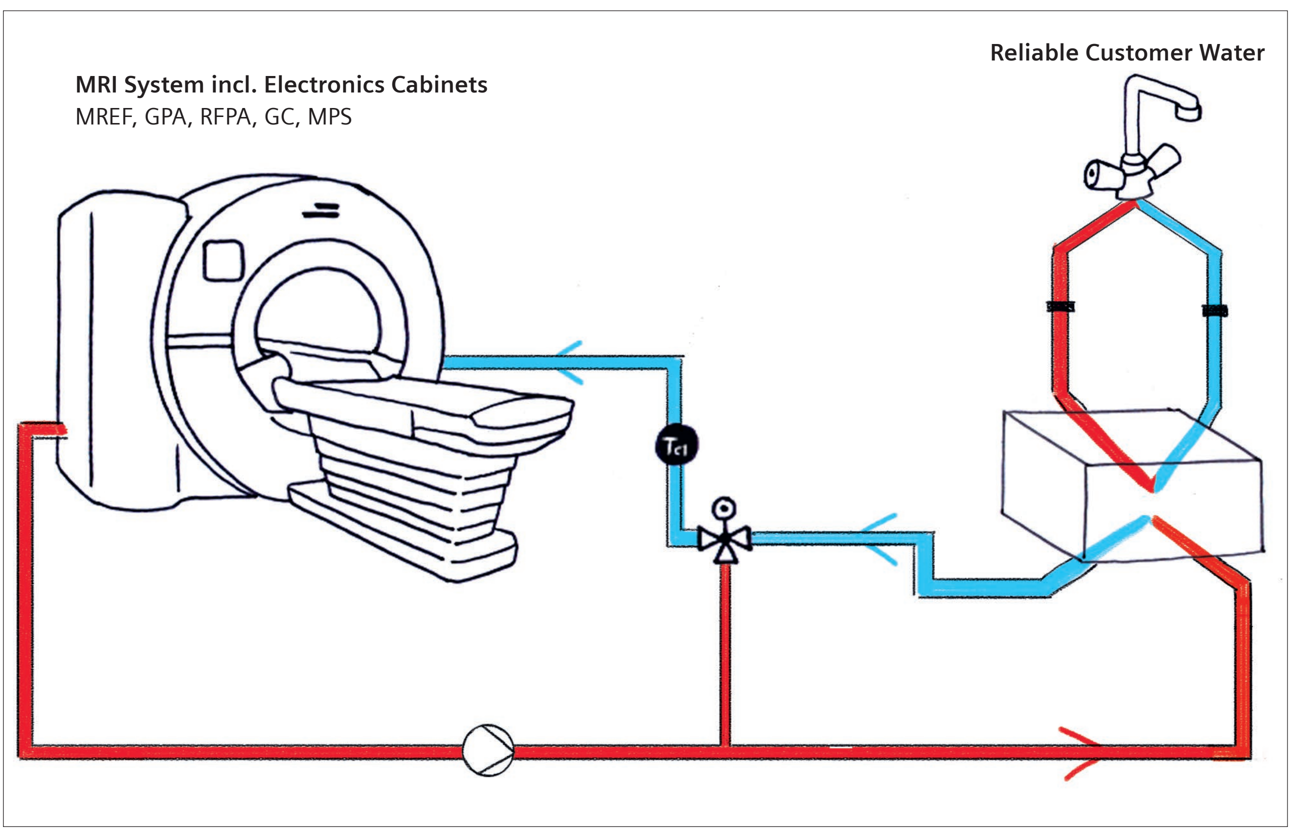
require up to 33 kW of cooling power, with demand primarily coming from the gradient system (coil and amplifier), the magnet cooling, and the RF amplifier. The cooling power is provided by two separate ~17 kW outdoor units (Siemens Outdoor Unit: SOU 1 and SOU 2; Fig. 2), which can work mostly independently from one another. During times when the system is in standby or scanning with less power-demanding sequences (TSE, GRE), only one of the two chillers is needed and the other one is turned off to save energy. If there is a failure with one of the 17 kW chillers, the second one automatically takes over to guarantee a permanent cold water supply and avoid a magnet ramp-down and the associated system downtime. The system can even continue scanning in this mode. Furthermore, during normal operation when one chiller is enough, the chillers are switched on and off in alternating mode to make sure both chillers are always operational and the energy consumption is optimized.

The splitting of the cooling modules requires little additional effort, as the 33 kW cooling power is needed anyway for system operation. This means that there is no extra cooling power added to provide redundancy for the magnet cooling, because the 6–8 kW required for magnet cooling is less than half of the total cooling power of a single unit. Redundancy can therefore be achieved just by providing the overall cooling power from two separate units with half the total system power – without the need to install any unused cooling power, which would add extra effort and costs.

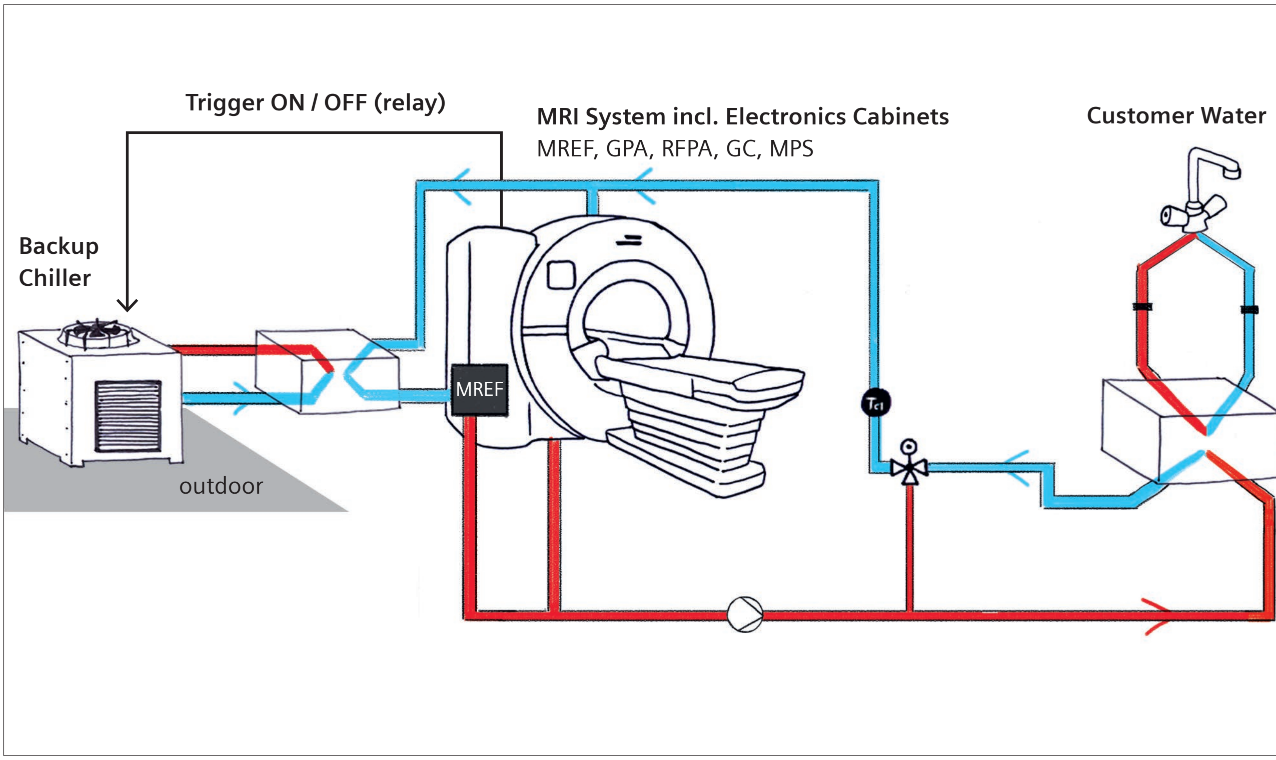
Passive cooling system

In many large institutions, cooling water is centrally supplied and the MRI system can profit from the fact that no extra chillers are needed. The so-called "passive cooling option" cools the MRI system using a heat exchanger which separates the water provided by the central cooling supply from the water circulating through the MRI system components (Fig. 3A).

In cases where the central water supply from the hospital is not considered to be reliable enough, there is also a possibility to connect a locally sourced "backup chiller" to the system. This can provide the cooling power needed to keep only the magnet refrigeration running in case the central water supply fails. The cold water for the MREF coming from the backup chiller is provided to the system through an additional heat exchanger. The system automatically detects cases where the cooling power from the central water supply is insufficient and sends a signal to trigger the backup chiller (Fig. 3B).



3A Passive cooling system with reliable water from a central customer supply.



3B Passive cooling system with automatically triggered backup chiller.

Remote monitoring and service

Despite the best efforts to ensure high reliability, cooling systems with high water flow rates and pressure – such as those used in MRI systems – require regular service. With the MR cooling system running 24/7, most failures (leakage, clogging, corrosion, dirt on outdoor units) can be detected and solved by qualified service personnel before they cause the system to stop working. Furthermore, the built-in cooling system is connected to our online service and all parameters available via sensors are also transmitted and evaluated online to allow remote diagnostics and preventive maintenance. In particular, the magnet refrigerator (MREF) is equipped with sophisticated temperature and pressure sensors. Preventive maintenance makes it possible to detect problems by watching the trends of these parameters over time. As a result, many problems can be detected before they lead to a complete failure of a component.

Summary

The above overview shows how the system architecture, both for the cooling system and the system control, is tailored to deal with the new challenges of DryCool magnets and deliver maximum availability. Three different configurations are provided to achieve a high-reliability cooling system adapted to the individual needs and conditions of different sites. The basic principle is to provide redundancy for those parts that have an unacceptably high chance of failure. Combining this with remote monitoring, regular servicing, and automatic ramping guarantees extremely high availability for DryCool systems and independency of the scarce natural resource helium.

Reference

1 Calvert S. MAGNETOM Free.Max: from Concept to Product, a Brief History of the DryCool Magnet Development. MAGNETOM Flash. 2021; MAGNETOM Free.Max special issue: 44–48. Available from: https://www.magnetomworld.siemens-healthineers.com/hot-topics/lower-field-mri

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