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Advanced Induction Materials and Technology

Online Induction Heating Course

2. Induction Installations

by. Dr. Valentin Nemkov

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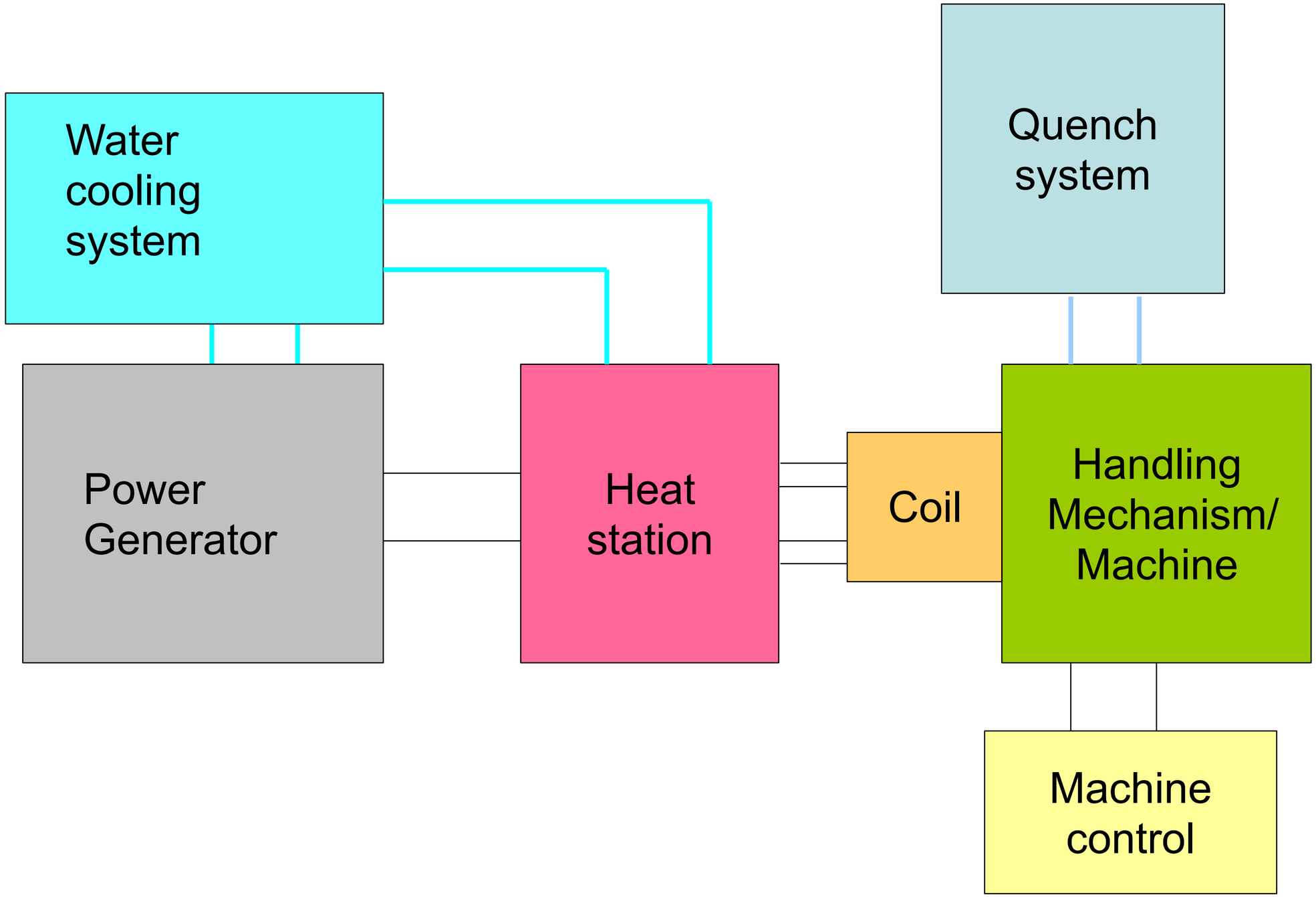
Induction Installation Structure

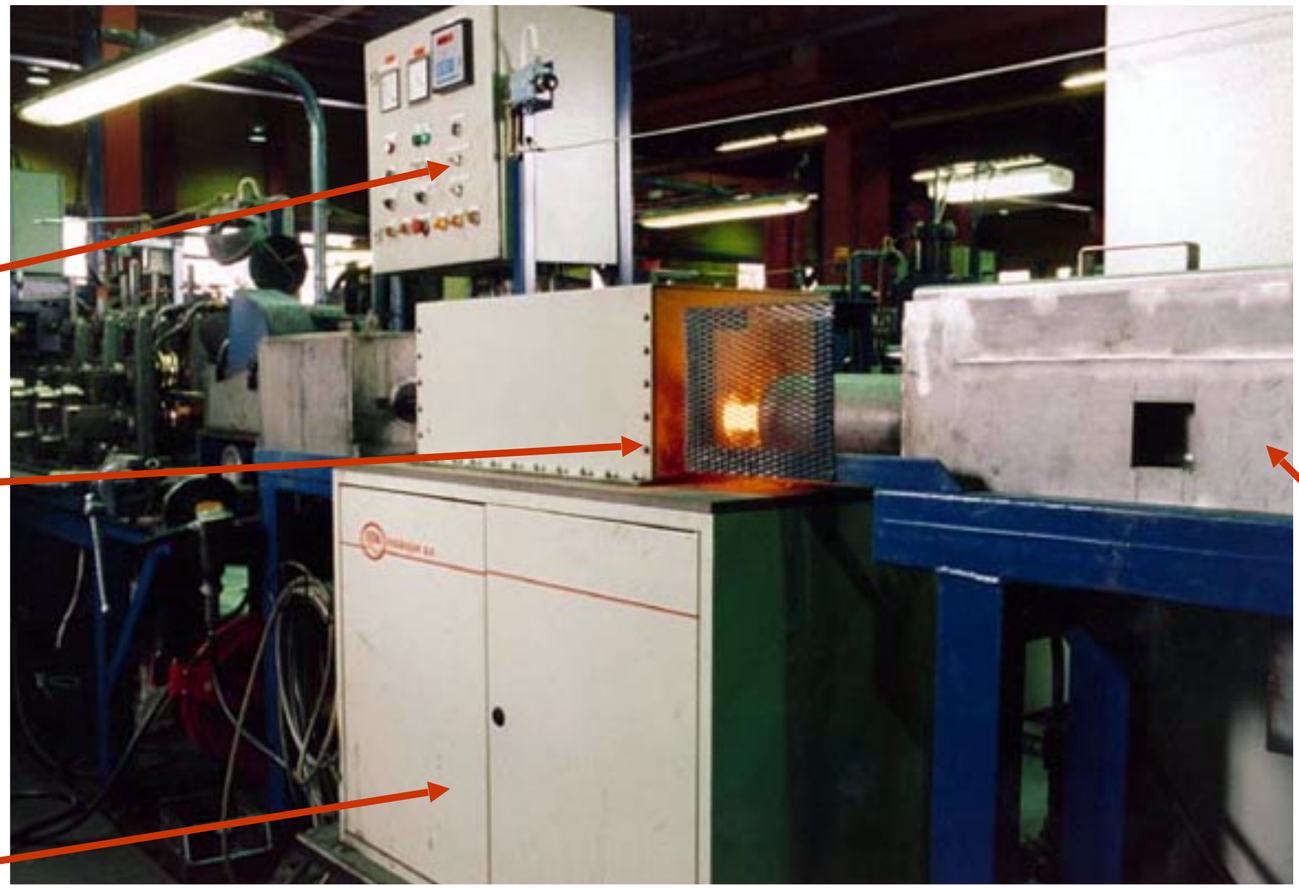
Main components of a typical induction installation:

- Generator: generates high frequency power from utility line frequency power
- Heat Station: matches induction coil to a generator
- Handling Mechanisms: load, process and unload parts
- Cooling System: provides cooling of installation components (generator, heat station and induction coil)
- Quenching System: provides conditioned quenching media to the part
- **Control and monitor systems:** provides control and monitoring process and equipment

Layout of Induction Hardening Installation



Installation with Coil Mounted on Heat Station

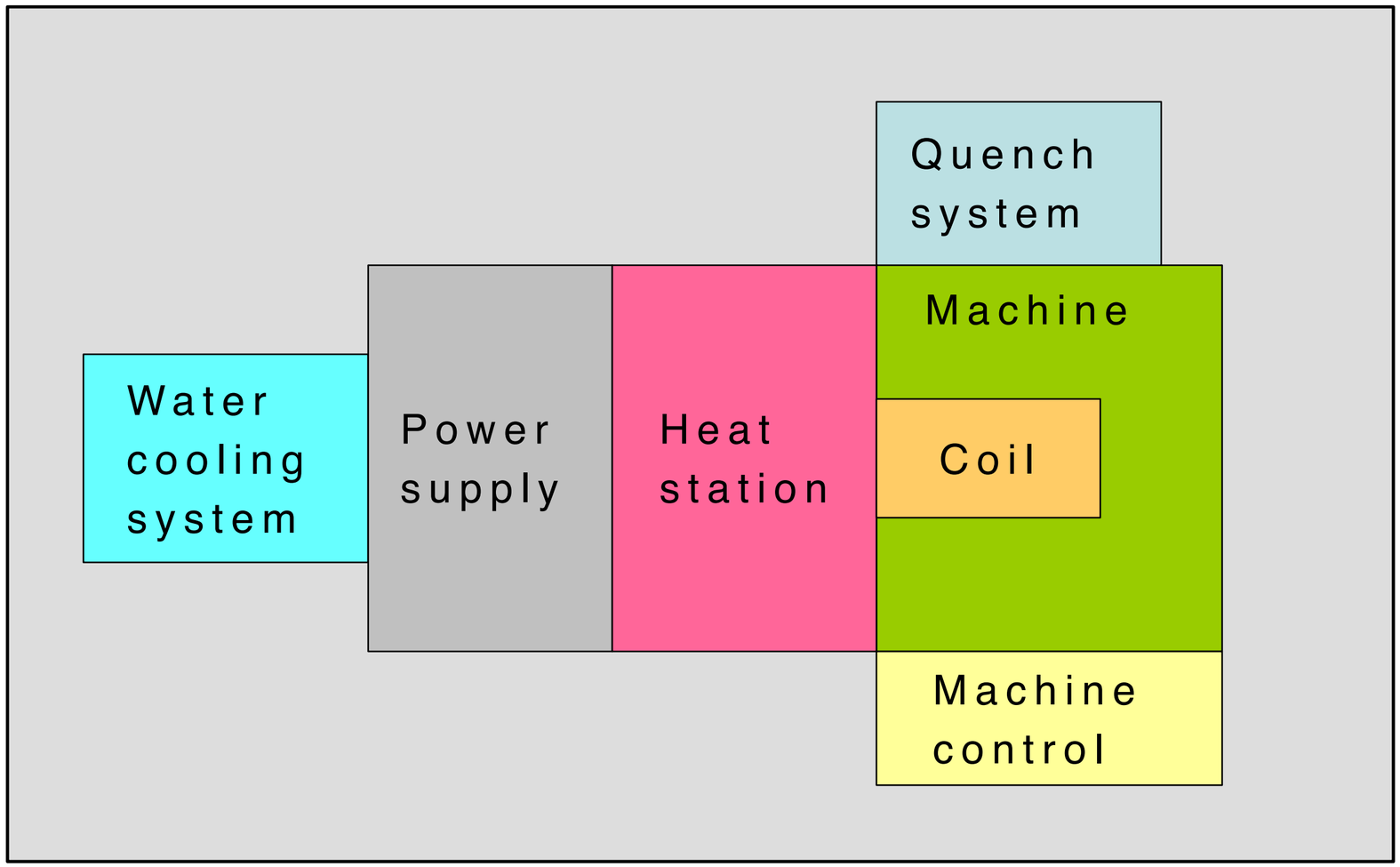


Courtesy of EFD Induction

Single Platform Installation

Induction installation may be:

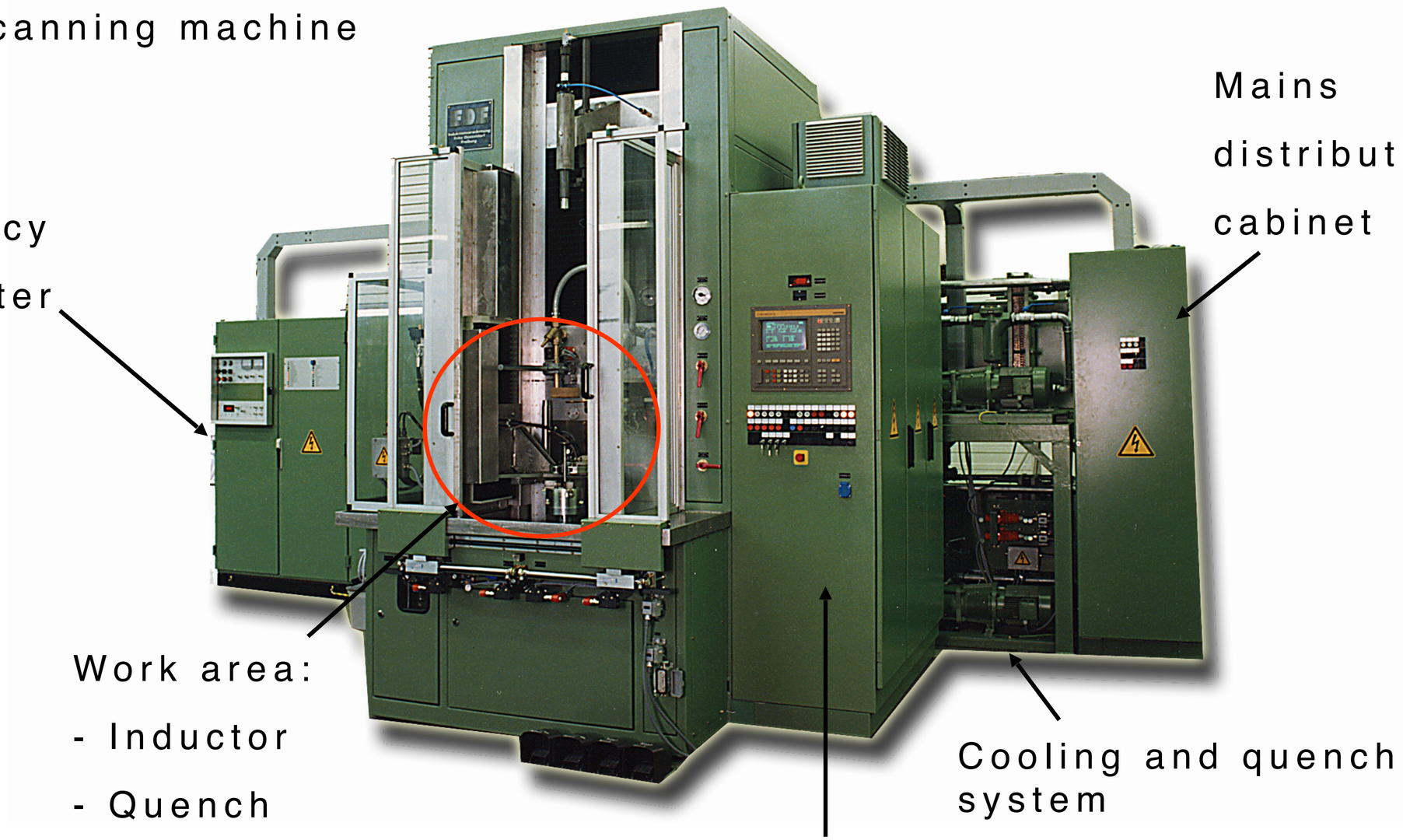
- Mounted on a single platform
- Distributed
- Built in line



Single Platform Induction installation:

- Requires less space
- Easy to install
- Shorter installation time
- Less expensive to install
- Utilities required at single point

Induction Hardening Installation



Example of a single-platform induction hardening installation,
EFD Induction

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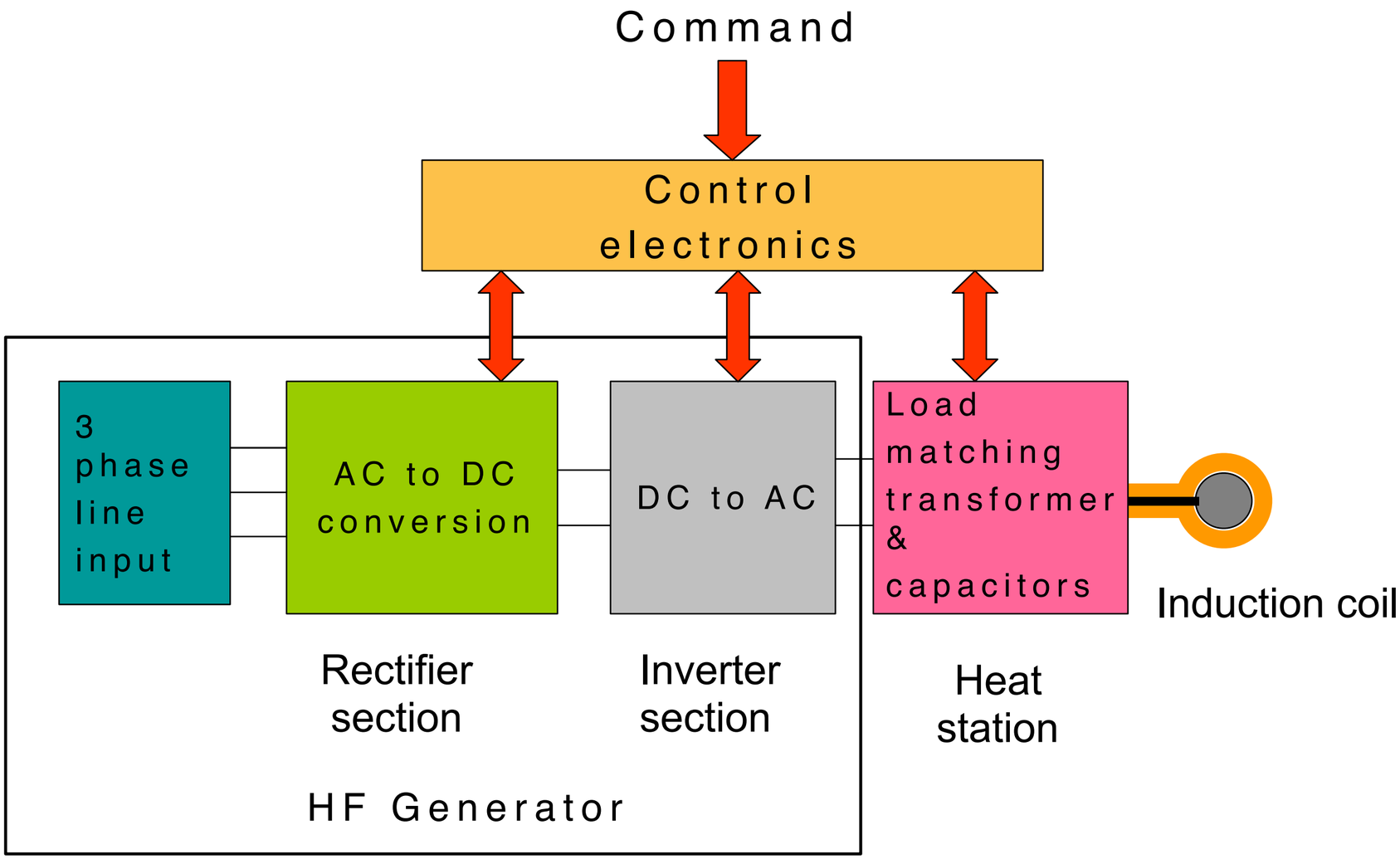
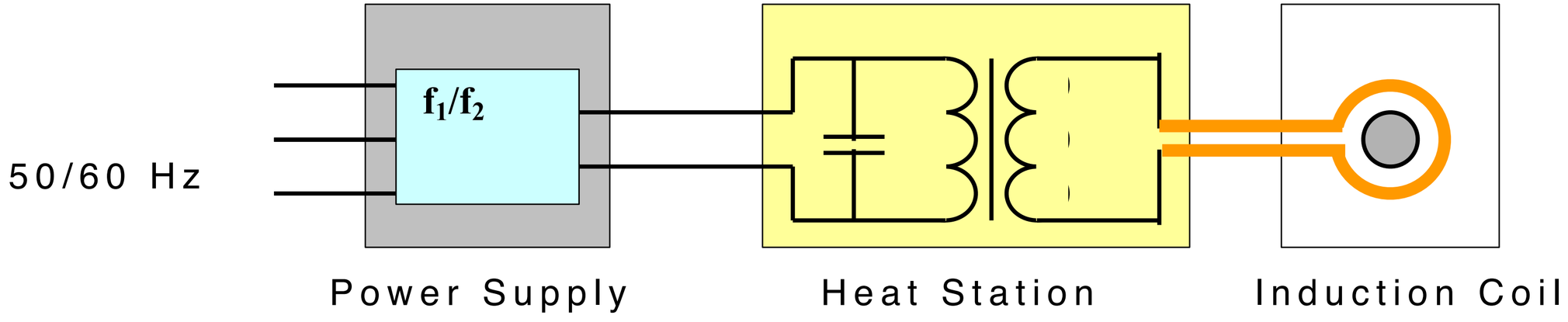
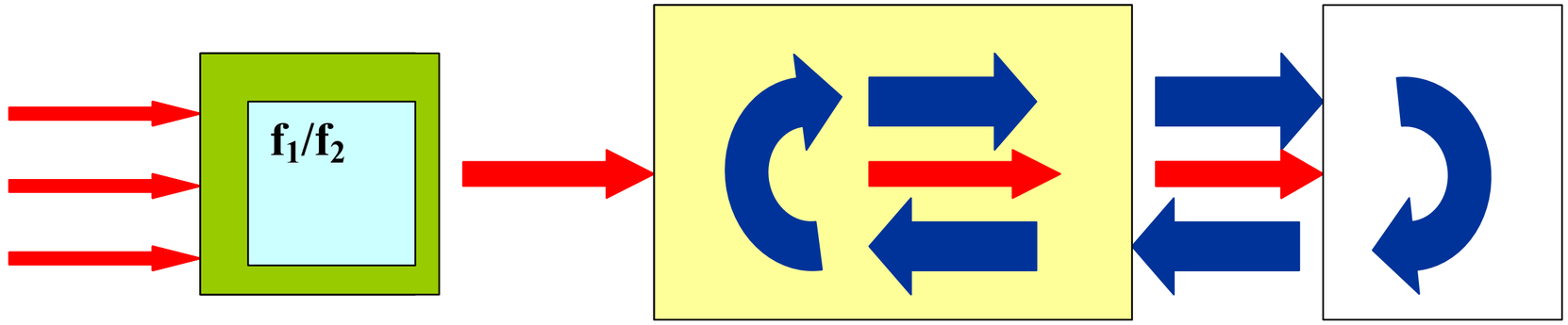
Power Supply Block Diagram



Power supply must convert alternating line frequency power (50 or 60 Hz) into a controlled High Frequency power. The most effective way to do that is to convert (rectify) line frequency power into DC power and then generate high frequency using solid state Inverter.

Power Flow in Induction Heating Installation





Active Power, kW

Reactive Power, kVA

See Glossary and Basics of Induction Heating for more details

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Types of Power Supplies

Power Supplies convert line power (50/60 Hz) to controlled power at frequency, current and voltage required for proper induction coil operation. They contain frequency converter (generator) and power matching system.

Types of frequency converters:	When developed:
• Motor-Generators	the 20's
• Vacuum Tube Generators	the 20's
• Solid State Generators	
• Thyristor Generators	early 60's
• Transistor Generators:	
- IGBT Generators	early 80's
- MOSFET Generators	mid 90's

Recent developments of solid state power supplies include:

• Dual Frequency Power Supplies	late 90's
• Intelligent Power Supplies	late 90's - 2000s

Motor-Generator Sets

- Obsolete equipment but still used in industry
- Frequency limited up to 10 kHz
- Fixed frequency, no ability of load matching by frequency variation
- Power from 50 – 2500 kW
- Efficiency - 65 to 85 %
- Output voltage from 400 – 1600 Volts
- Rotating parts require maintenance due to wear and tear
- Big size and weight
- Difficult to repair

Vacuum Tube Generators

- Also known as Radio Frequency Oscillators
- Frequency range from 60 kHz to 400 kHz and higher (highest known frequency used for Induction heating – 27.12 MHz)
- Low efficiency - 50 to 60 %
- Very high voltages (up to 20 kV) require special safety precautions
- Limited life of vacuum tube (several thousands hours)
- Expensive vacuum tube replacement
- Easy load matching
- Can provide high **Power Pulses** with power densities on the part surface above 30 kW/ square inch
- Can easily operate with loads having low power factor (big reactive power)

Welder with vacuum tube oscillator, EMMEDI company

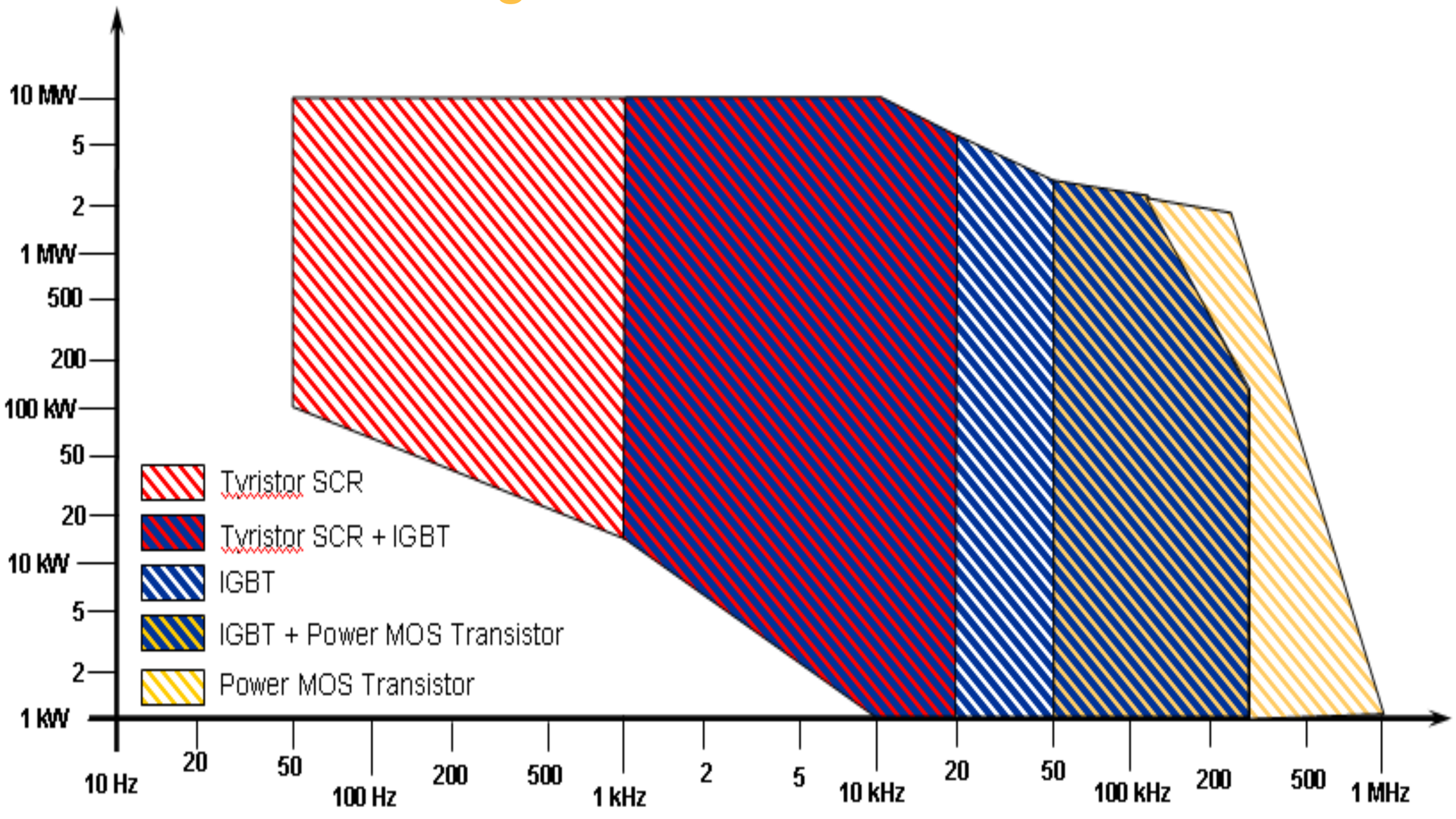
Solid State Generators

- Any reasonable combination of frequency and power is possible
- Variable frequency in a range up to 10 times from the same generator with proper changes in heat station
- Power from 1 kW – 10 MW
- Output voltage from 200 – 1600 Volts
- High efficiency - up to 90- 95 %
- Multiple outputs possible
- Simultaneous dual frequency output possible
- Advanced controls
- Easily adaptable to modern automation techniques
- Light weight and compact size

Power supply 100 kW,
10 or 30 kHz
Inductoheat Inc.

2 Induction Installations

Modern Solid State Power Supplies
Big and Middle Sizes



Courtesy of EFD Induction, Inc.

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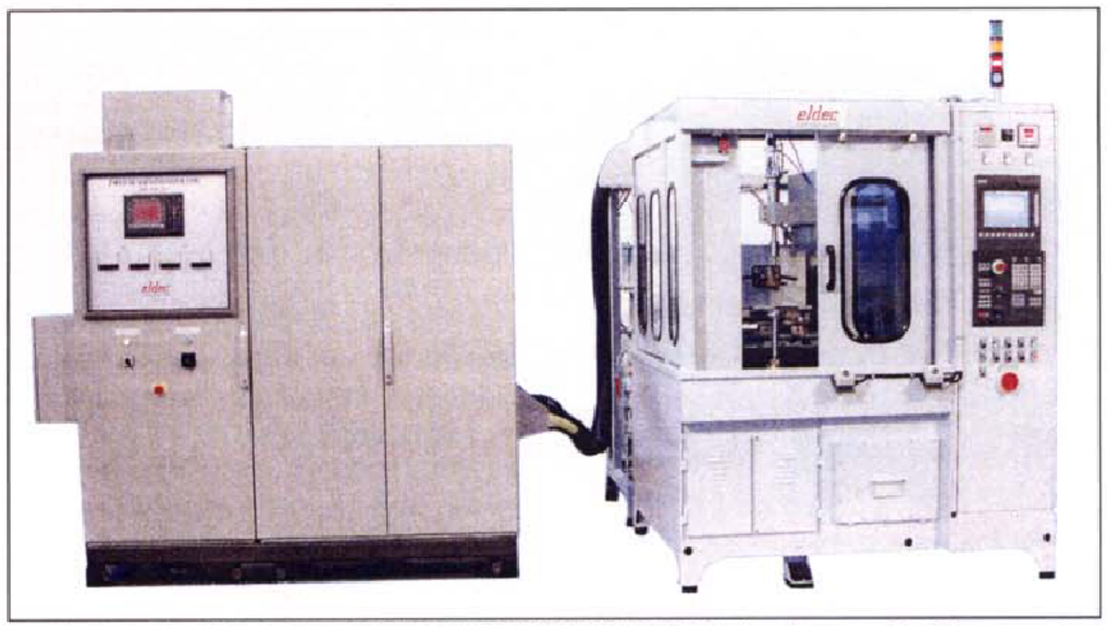
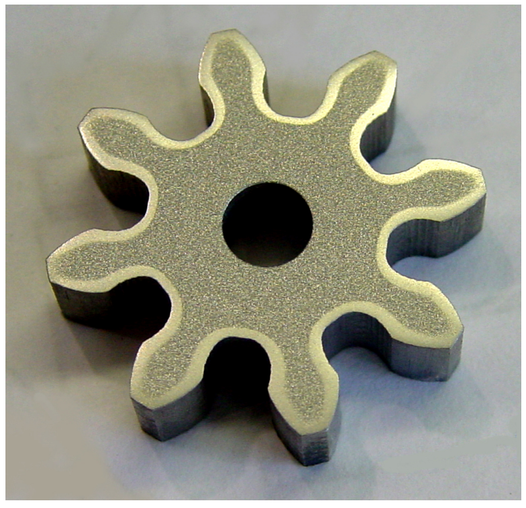
Simultaneous Dual Frequency Power Supplies

For contour hardening of gears and other parts of complex geometry, special transistor power supplies were developed that can generate two frequencies simultaneously. Power levels may be programmed independently for each frequency, providing accurate results and high process flexibility.



600 kW induction hardening machine with variable ratio of Middle Frequency power (up to 400 kW) MF and High Frequency power (up to 200 kW), Eldec Induction U.S.A. Inc.



Gear hardened by means of Simultaneous Dual Frequency Heating

Intelligent Power Supplies

Modern power supplies can deliver almost any combination of power and frequency; they have high efficiency and small size.

The main tendency of further development is improvement in flexibility and controls leading to more intelligent machines.

Modern induction power supplies can provide:

- Power generation in a wide range of frequency
- Autotuning with coil change and coil parameter variation in the process of heating
- Process programming
- Control from Master control system of the production line
- Process monitoring
- Automatic troubleshooting
- Remote control and diagnostics including actions from the manufacturer site

Development of more advanced and sophisticated control systems may be expected including real-time process optimization and quality

Comparison of Power Supplies

Type of Power Supply	Switching device	Frequency range	Efficiency of power supply %
Line frequency	None	50/60 Hz	93 - 97
Motor-Generator	None	1 kHz –10 kHz	70 – 85
Solid state	SCR Thyristors	500 Hz – 25 kHz	87 - 95
Solid state	IGBT Transistors	1 kHz – 200 kHz	85 - 92
Solid state	MOSFET Transistors	100 kHz – 400 kHz	85 – 92
Vacuum Tube Generator	Vacuum tube	66 kHz – 500 kHz and more	50 - 60

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Large Solid State Power Supplies / Application Areas

Category	Low Frequency (LF)	Medium Frequency (MF)	High (Radio) Frequency (HF)
Frequency Range	50 Hz to 3 kHz	3 kHz to 60 kHz	Above 60 kHz
Power Range	Up to 30 MW	Up to 5000 KW	Up to 1800 KW
Applications	Melting Mass Heating	Mass Heating Heat Treating	Heat Treating Bonding Brazing Tube welding

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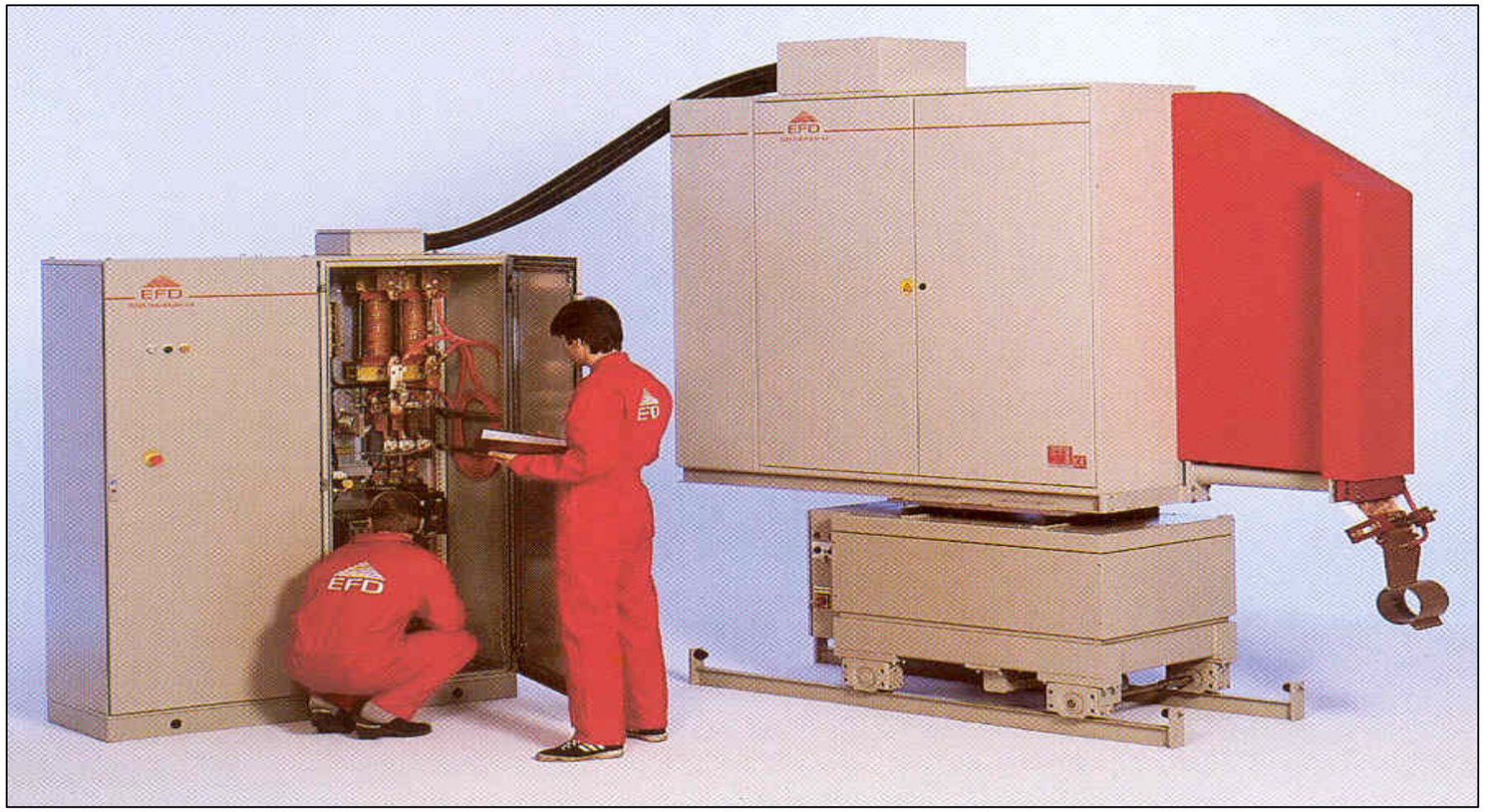
Large High Frequency Solid State Power Supply

Power range:

150 – 1800 kW

Frequency range:

100 – 400 kHz



MOSFET power supply (welder) for continuous tube welding

Courtesy EFD Induction, Inc.

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Mid-Sized Solid State Power Supplies / Application Areas

Frequency Range	3 kHz – 500 kHz
Power Rating	30 KW – 500 KW
Applications	Induction Hardening Melting Brazing Mass Heating Tube Welding
Innovations	Protection against environment Intelligent digital control systems Process or coil monitoring Dual output available (Synchronized or Independent)

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Small Solid State Power Supplies / Application Areas

Frequency Range	20 kHz – 500 kHz
Power Rating	1 kW – 25 kW
Applications	Induction Hardening Induction Brazing Shrink fitting Melting
Innovations	Air cooled Self tuning Intelligent digital controls Compact and low weight Dual independent output available Portable and handheld units available Use of flexible cables for easy handling

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Small Solid State Power Supplies

These power supplies are widely used for a variety of applications requiring high frequency and relatively small power such as:

- Melting
- Hardening
- Brazing
- Soldering
- Shrink-fitting etc.

Generators are typically air-cooled while heat stations have water cooling.

Individual heat exchangers or chillers become more and more popular

2kW, 150 - 400 kHz power generator with heat station and chiller, Ameritherm Inc.

Dual Output Solid State Power Supplies

Dual Output Power Supplies can work in one of the following work modes:

Alternating duty

- Utilizing one output at a time
- Full power available on each output
- Common inverter and control system

Parallel duty

- Utilizing both outputs at the same time
- Output power divided by the output transformers
- Common inverter and control system

Twin Output

- Two outputs with independent operation and controls
- Common DC but two inverter sections
- Outputs could be at different frequencies

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Dual Output Solid State Power Supply

Controls &
Meter Display

- Power 18 / 25 kW
- Frequency 10-25 kHz
- Dual Independent Outputs
- Hand Held Transformer
- Flexible Cables

Induction Coil

Transformer

Minac 18 TWIN power supply, EFD Induction

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Power Supply Selection Criteria

- Frequency
- Power rating
- Output voltage range
- Output current range
- Load matching capabilities
- Controls
- Efficiency
- Reliability
- Floor space
- Easy to operate and maintain
- Initial cost and repair cost
- Manufacturers experience and reputation

Load Matching

Any electrical energy recipient (bulb, motor, heater etc.) can effectively work at certain frequency, voltage and current values.

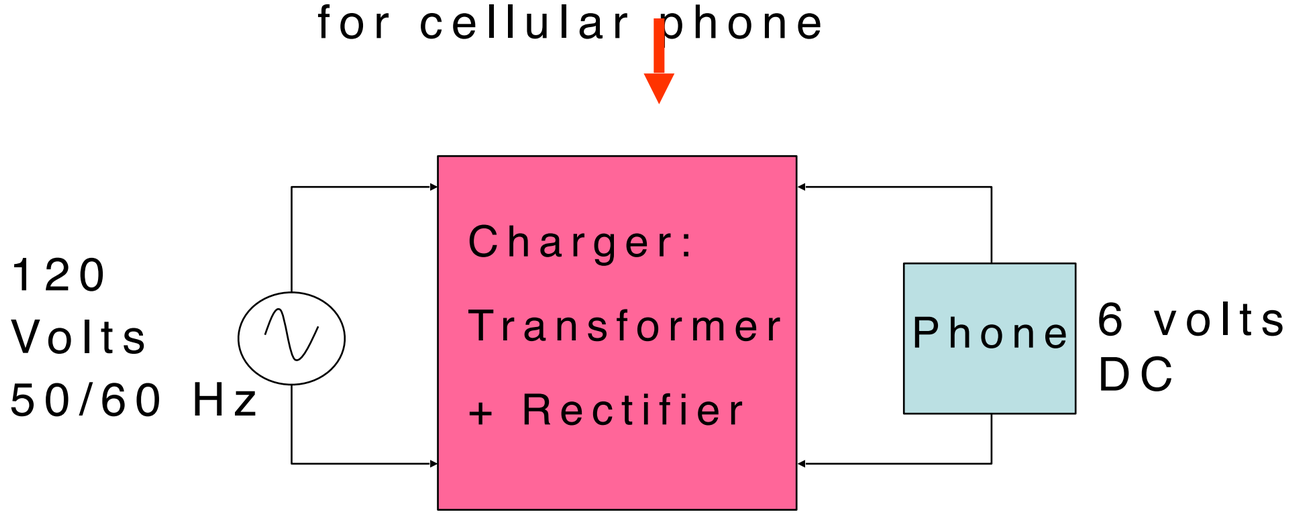
For electronics and appliances, matching is provided by chargers.

For induction coils there are two matching devices:

-Transformers provide voltage matching

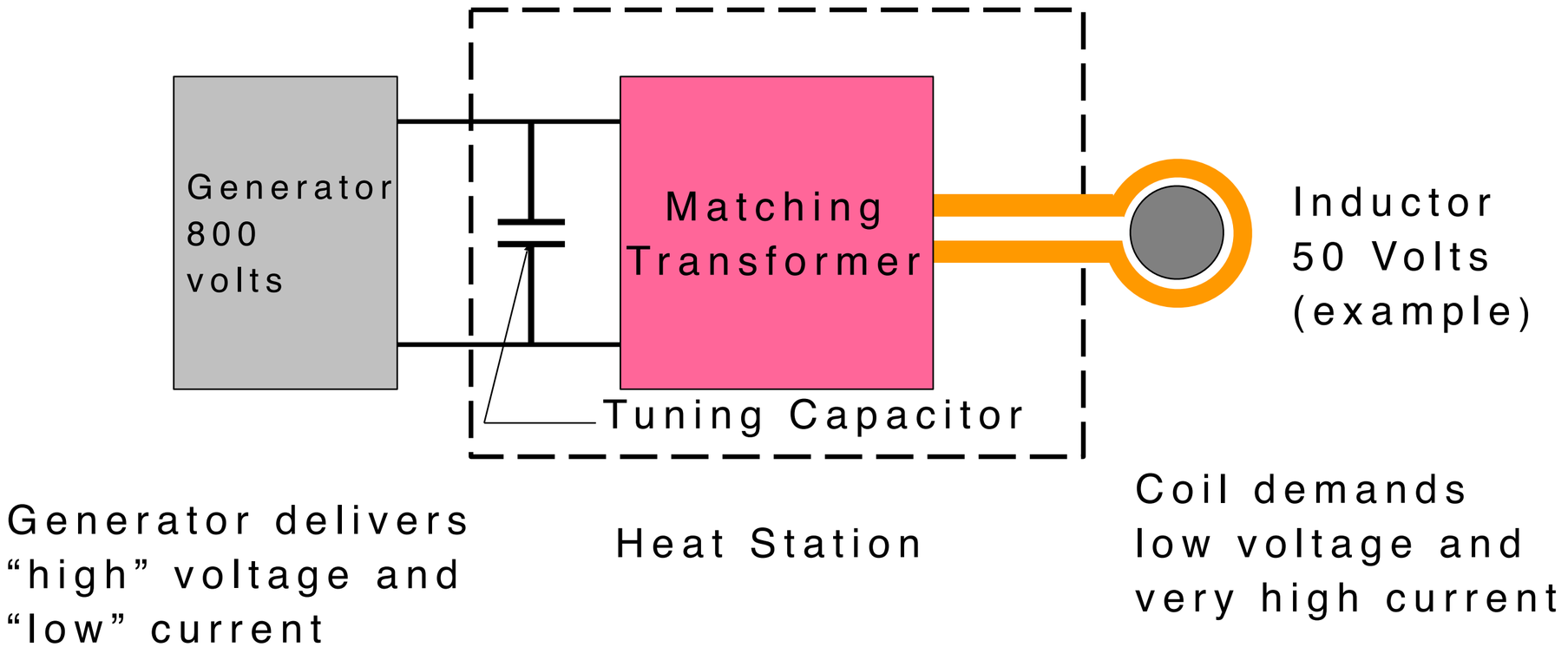
- Capacitors compensate (reduce or eliminate) the coil reactive power

Example of matching device for cellular phone



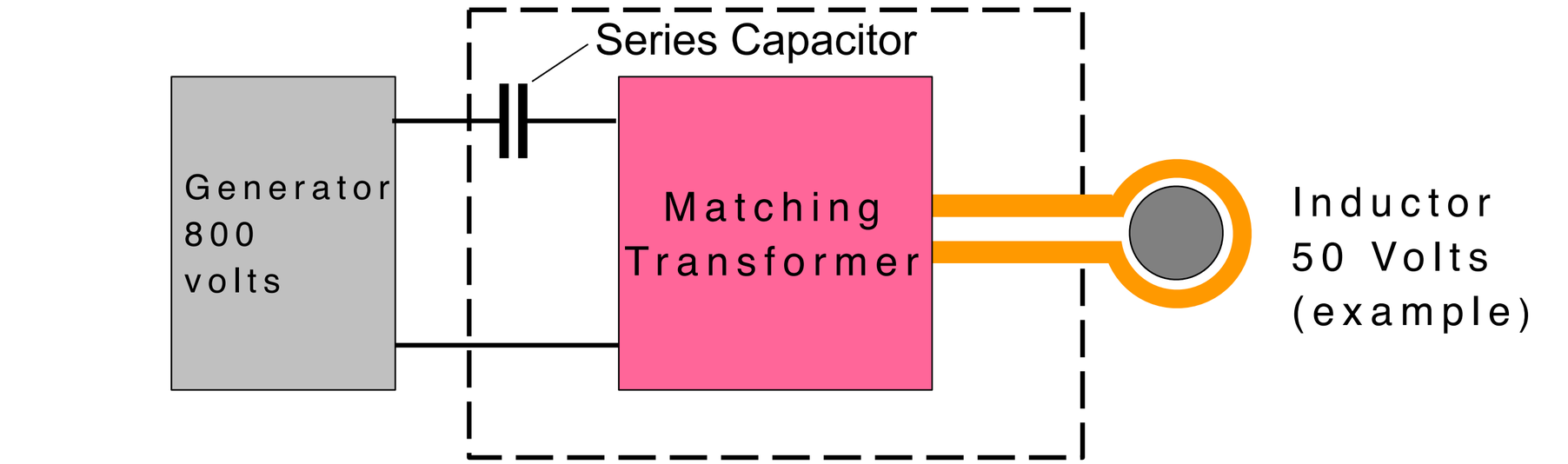
Load Matching with Parallel Circuitry

- Generators with parallel circuitry produces relatively “high” output voltage and “low” output current
- Coils require very high current at “low” voltage
- Transformer reduces generator voltage to required level
- Capacitor battery is necessary to compensate reactive power of the coil; it reduces generator current to required value due to “parallel resonance”
- With the proper load matching power supply could deliver maximum available power to the coil at required voltage and current



Load Matching with Series Circuitry

- Generator produces “low” output voltage and “high” output current
- Coils typically require even higher current at low voltage
- Transformer reduces generator voltage and increases current to required level
- Capacitor battery is necessary to compensate reactive power of the coil; it reduces transformer primary voltage to required generator output value due to “series resonance”
- With the proper load matching power supply could deliver maximum available power to the coil at required voltage and current

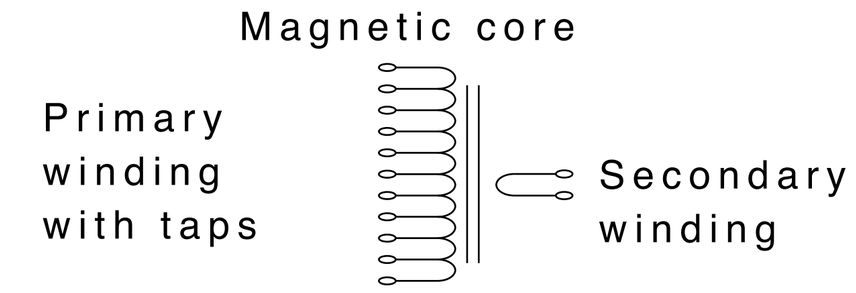


Heat Station

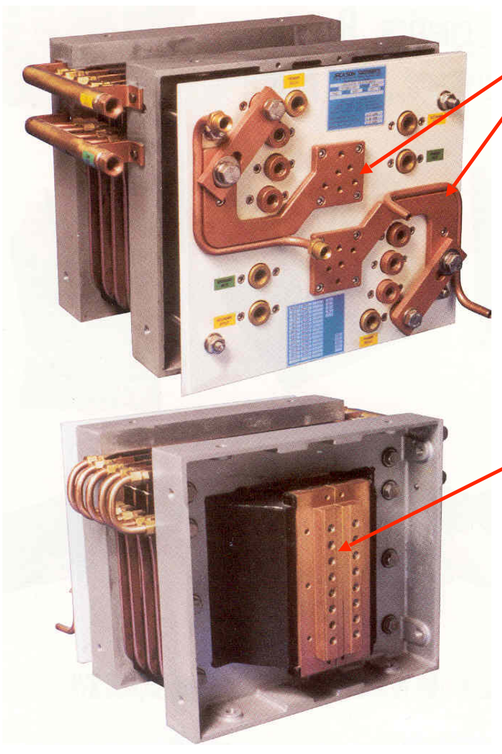
- Utilized to match induction coil voltage & current to output voltage & current of generator
- Heat Station may contain:
    - Matching transformer
    - Tuning capacitors
    - Water cooling circuit components
    - Water pressure gauges and switches
    - Water temperature switch and other monitoring and control devices
- In small solid state power supplies heat station may be housed inside the power unit for compactness, loss reduction in bus/cables and lower cost

Load Matching Transformers

- Transformer provides voltage matching of generator output and induction coil. It is similar to a gear box in the car
- In some cases transformers are necessary for safety (isolation transformers). They prevent line or DC voltage appearance in the coil circuit
- Some multi-turn coils such as mass heating coils, may not require usage of step-down transformers
- There are cases when step-up transformers must be used (coil voltage is higher than generator voltage)
- Low and Middle frequency transformers have magnetic circuit made of laminations



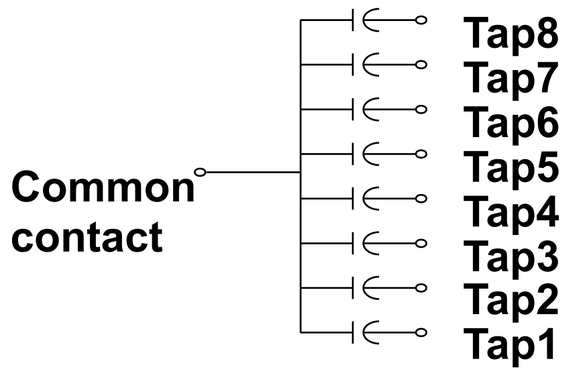
Layout of variable-ratio transformer



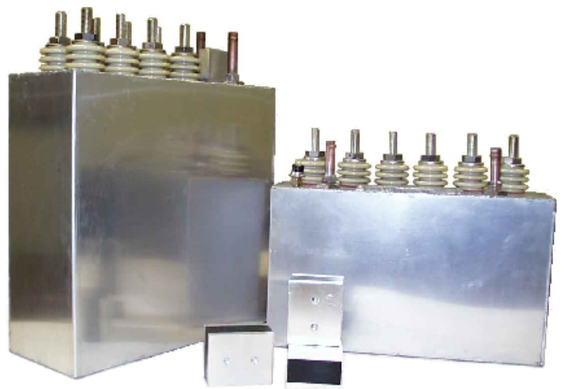
Variable ratio middle frequency transformer, Jackson Transformer Co.

Capacitor Battery

- In induction heating applications, capacitors are used to compensate for the reactive power of the induction coil
- Capacitor batteries are made of individual capacitors connected in parallel, series or series-parallel
- Capacitor ratings are capacitance (mkF), voltage, frequency, current, kVArs, number of taps
- Used also to set up the load resonant frequency (see Glossary)
- Capacitance must be increased to reduce resonant frequency and vice versa
- Capacitors may be water-cooled, conduction-cooled or air-cooled



Layout of capacitor with variable capacitance



Water-cooled oil-filled capacitors for induction heating, High Energy Corp.

CELEM conduction-cooled capacitors

Load Matching Procedure

For coil matched all three parameters (frequency, current and voltage) must be in rated range of power supply. Operating frequency must be close to a resonant frequency of the tank circuitry, which can be calculated as

$$F = 0.16/\sqrt{(LC)}, \text{ kHz}$$

with L – coil inductance in mkH

C – capacitance in mkF

Step	Controlled Parameter	Recommended Value	Actual Value	What to do?
One	Frequency	Inside of Rated Frequency Range	Low	Reduce capacitance
			High	Add capacitance
Two	Voltage	Both Voltage and Current should be in the same level of value to have high power	High	Lower transformer ratio*
	Current		High	Increase transformer ratio*
	Power	Maximum required	Low	Either increase voltage or current

* Possibly it would be necessary to repeat Step 1 after changing the transformer ratio

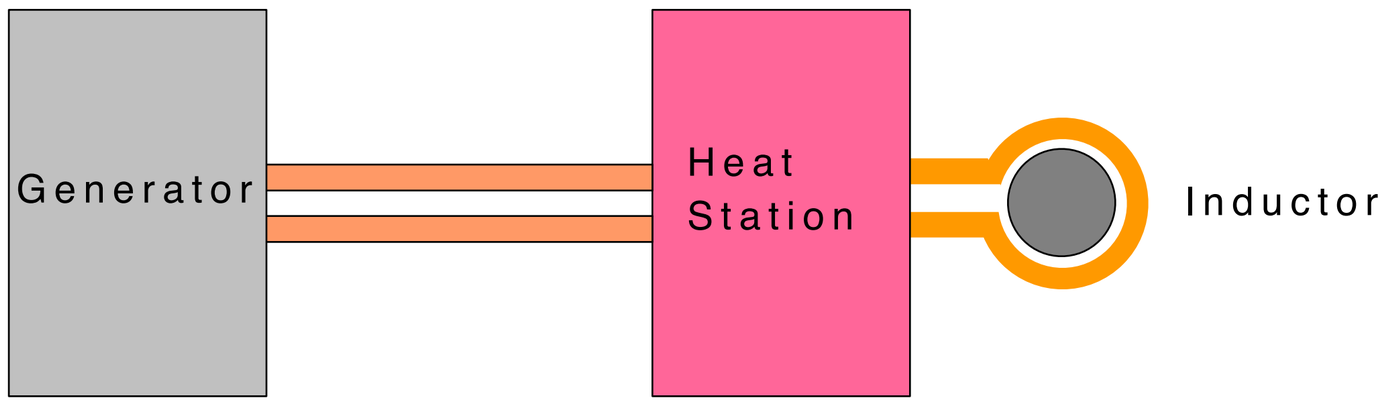
Power Supply Regulation Modes

Many modern power supplies can work in different operation modes, keeping constant output voltage, current or power. These parameters may also be programmed in time.

Regulation Mode	Power	Voltage	Current
Power regulation	Set to regulate	Variable until maximum limit is reached	Variable until maximum limit is reached
Voltage regulation	Variable until maximum limit is reached	Set to regulate	Variable until maximum limit is reached
Current regulation	Variable until maximum limit is reached	Variable until maximum limit is reached	Set to regulate
When voltage or current reaches maximum limit the generator may turn OFF or continue to operate tracking the limited parameter			

2 Induction Installations

Power Connections



Generator to Heat Station

- “Sandwich” buss bars for low frequency high power
- Litz cables for high frequency low power
- Water cooled flexible cables for low frequency high power
- Multiple water cooled flexible cables for high power long distance

Heat Station to Coil

- Water cooled copper buss for heat treating applications
- Water cooled flexible cables for long distance between heat station and coil especially for forging or melting application

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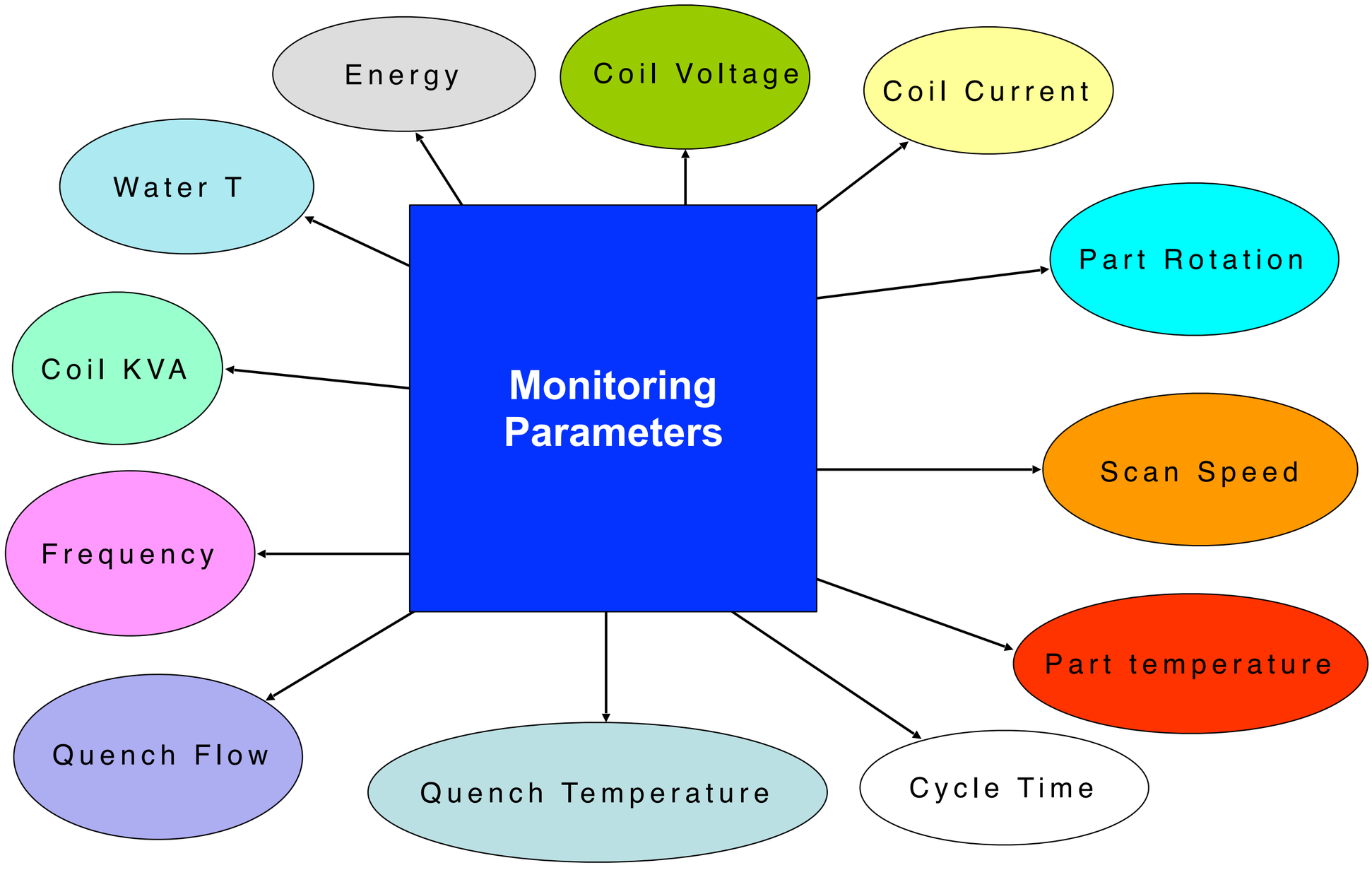
2 Induction Installations

Process Control and Monitoring



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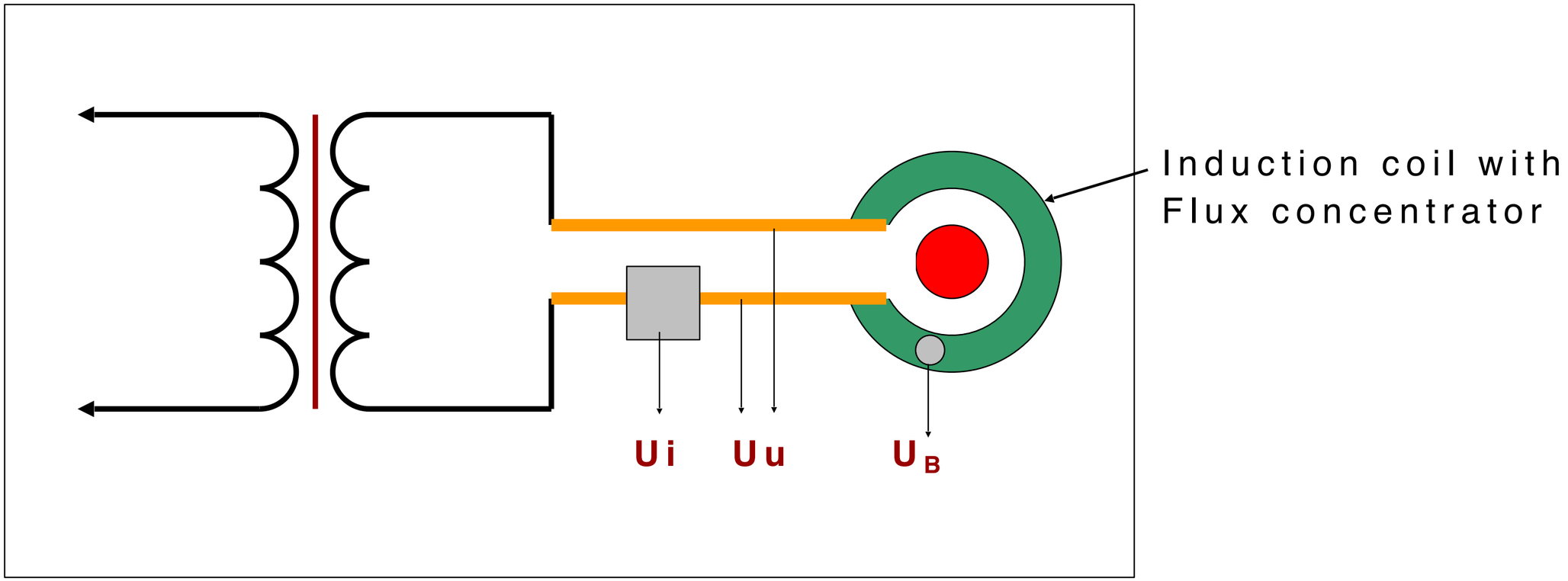
Layout of Induction Circuit with Sensors



Ui – Coil Current Signal

Uu – Voltage Signal

U_B – Flux Density Signal

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Process Monitors

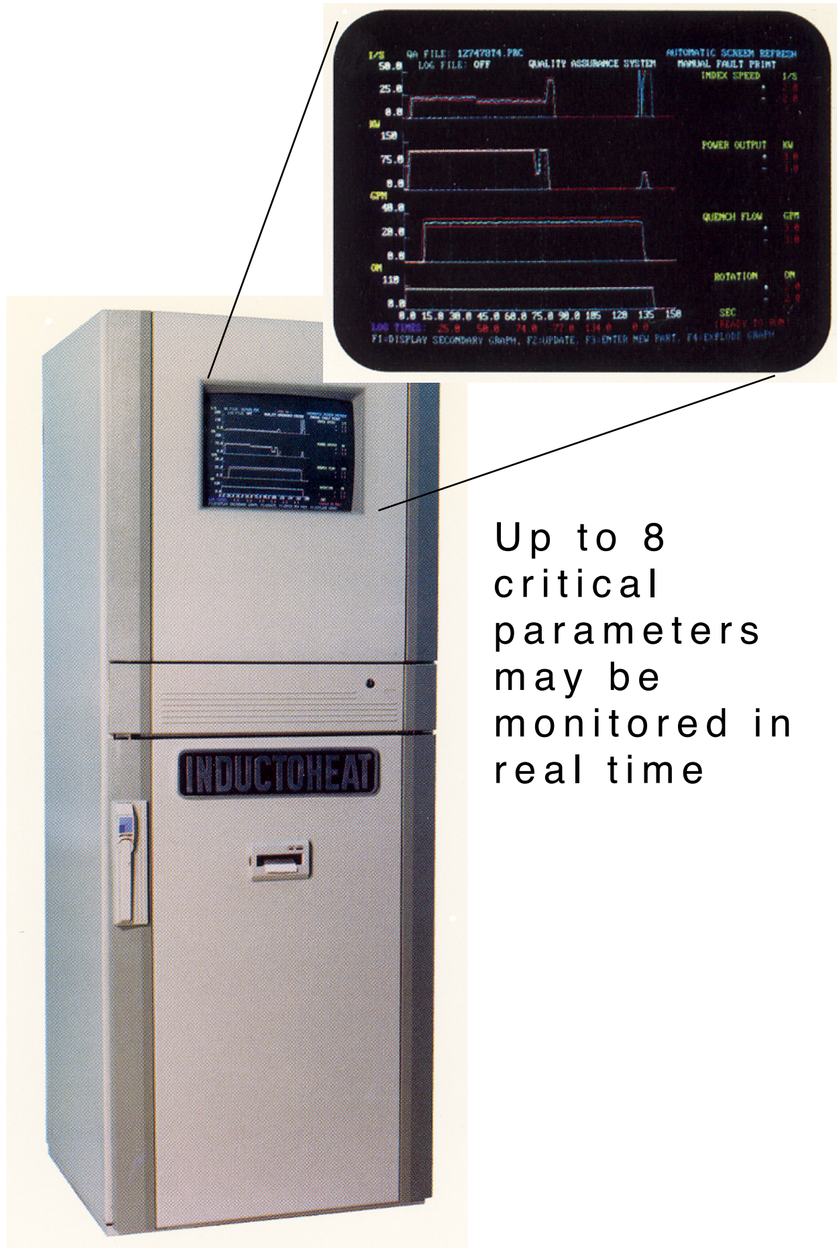
Process monitoring is one of the most important features of modern induction installations.

There are many types of monitoring systems from relatively simple coil monitors to sophisticated multi-functional devices.

Monitors can provide:

- Measurement of electrical parameters – current, voltage, power
- Part temperature control
- Control of part rotation and scan speed, cooling and quenching conditions etc.
- Process repeatability control and detection of faulty conditions
- Gathering information for data storage and trend analysis

Use of monitors improves quality control, facilitate troubleshooting, saves time and costs due to reduction of destructive tests



Up to 8 critical parameters may be monitored in real time

Quality Assurance Monitor, Inductoheat Inc.

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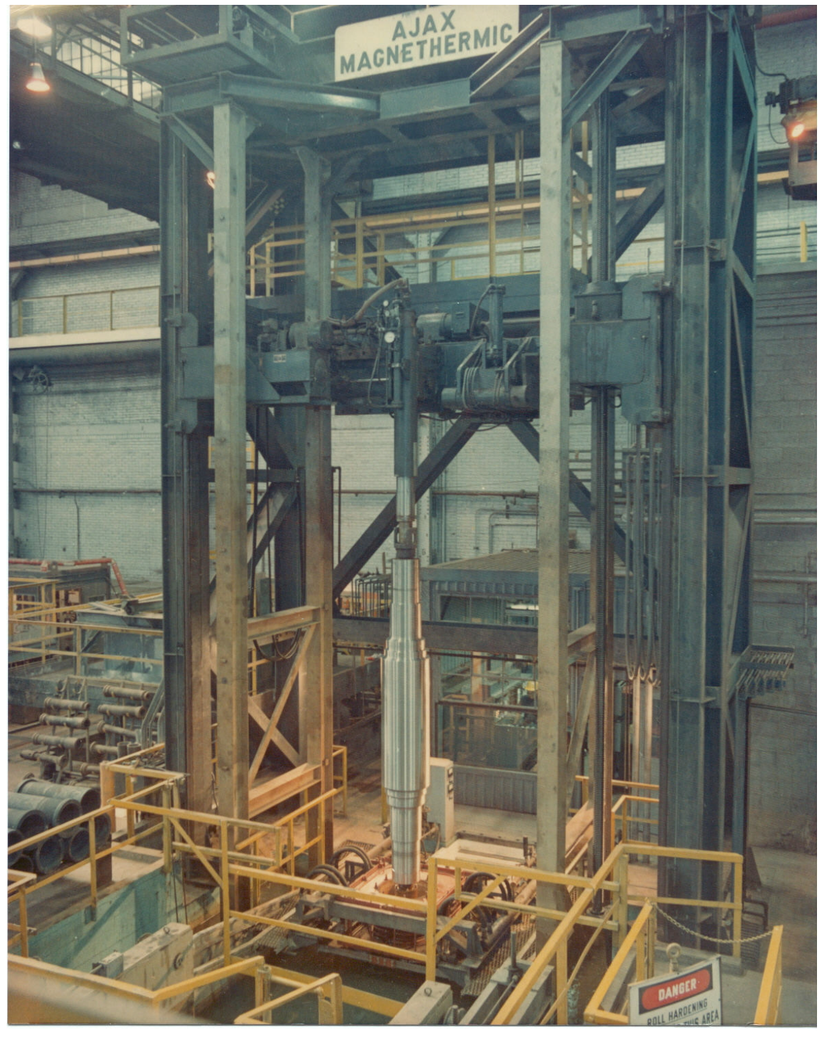
Part Handling Systems

- Different mechanisms are used for different part shapes and size and various types of processes
- For heat treating the following mechanical systems are usually used:
  - scanners
  - lift and rotate
  - conveyers
  - rotary tables
  - robots
- Part handling systems may be mechanical, pneumatic or hydraulic
- Control of heat treating machines may be based on relay logics, PLC or PC
- In modern lines the whole installation must be under the line **master** control and stronger requirements are set for process monitoring and reliable coil performance
- Different part handling and control systems require specific coil types and therefore different opportunities for Fluxtrol concentrator application



Installation for scan hardening of rolls with maximum diameter 30”, length 30 feet and weight 30,000 lbs., AjaxTOCCO Magnethermic Corp.

Water Cooling and Quenching

- Power losses in current carrying components generate heat. When losses are high these components must be water cooled. Generators up to 25 kW may be air-cooled with water-cooled heat stations and coils.
- Insufficient cooling is the main reason of premature component failure.
- The following general measures are used to provide reliable cooling:
  - Multiple water circuits to ensure sufficient water flow
  - Input and differential pressure control gauges
  - Water flow rate sensors
  - Temperature sensors in water input line and on various water-cooled components
- Induction coils and transformers require clean water with controlled min (to avoid condensation) and max temperature. Water must have low content of minerals or be demineralized (the best!).
- Some electronic components may require in addition deionized water to prevent current leakage and component erosion due to electrolysis. See manufacturer requirements!
- Two or even three water and quench systems may be used in one installation. They may be of open or closed loop type.

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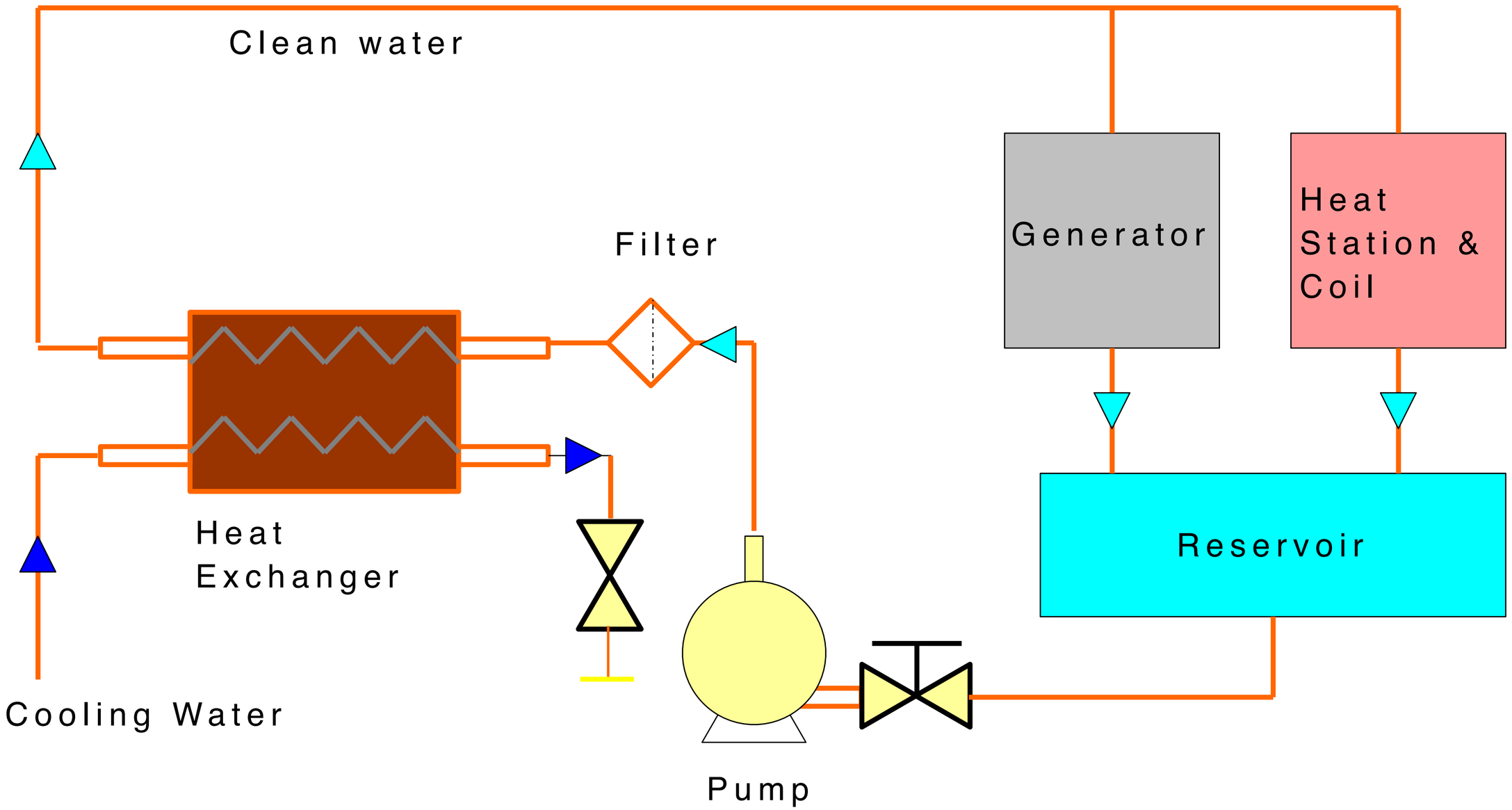
Typical Closed Loop Water Cooling System



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Conclusions

There are many installations now to choose from:

- Wide range of combinations “Power – Frequency”
- Wide range of types and design
- Choice of installations adapted to a variety of applications
- Choice of universal installations with good matching ability in wide frequency range

Modern power supplies may be:

- Small in size and weight
- Very efficient
- Easy to operate and maintain
- Adapted to automated systems

Flux concentrators on induction coils can improve the installation performance:

- Reduce coil power demand or increase production rate
- Reduce installation size and price
- Improve efficiency of power supply due to reduced coil current demand
- Reduce external magnetic fields (shielding!) resulting in:
    - Safer environment for operators
    - No interference to computerized control systems
    - No unintended heating of machine components
    - Eliminate “cross-talking” in multi-generator systems

Questions and Answers

- An induction Process can be defined by a combination of?
  Power, Time, Frequency
- In Induction Heating line power is converted from AC to DC and then back to AC for what reason?
  To achieve controllable output power at desired frequency
- What are the 3 main types of power supplies?
  Motor Generator, Vacuum Tube, Solid State
- What switching devices are used in solid state power supplies?
  Thyristors and Transistors
- What types of power supplies can generates two frequencies simultaneously?
  Dual Frequency and Twin Output
- The types of power supplies are?
  Alternating Duty, Parallel Duty, Twin Output
- Can line or DC voltage appear on the coil if it's connected to the power supply through a matching transformer?
  No
- What are the 2 devices in induction installations used for coil matching?
  Transformers and Capacitors
- A Capacitor Battery is required to compensate for coil ....?
  Reactive Power
- The components used to match the coil voltage and current to the output voltage and current of the generator are in the ...?
  Heat Station
- The taps on a transformer in the heat station are used to?
  Change transformer ratio and adjust output voltage
- What coil cooling water parameters it is necessary to control?
  Temperature, pressure , mineral content

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