Displacement variation, an overview of the methods offered by SAI
The market is always demanding an increase in the operational range of its machines, more torque, more speed and increased reliability!

At the same time, fuel economy and the reduction of heat generation are always equally, if not more, important.

Why is SAI the best solution to satisfy these requirements?

- We offer maximum efficiency among hydraulic components.
- We have a wide choice of advanced technological solutions for variable displacement control.
- The construction of SAI motors means that we can achieve a very low ratio between minimum and maximum displacement ($E_{\text{min}}$) – as low as 1:10 is feasible!!!
The SAI design allows us to vary the displacement in a number of different ways. Each of them offers different performance, include different hardware with differing degrees of complexity.
In SAI motors, the displacement change is done by varying the stroke ($2 \times e$) of the pistons, whilst keeping the bore and the number of “active” pistons unchanged. This makes it possible to change displacement in motion (on fly). The “reaction time”, or the time needed to change displacement, is specific for each application. SAI can supply motors with various reaction times.

**Displacement** = \( \frac{d^2}{2} \times \pi \times nc \times e \)

where:
- \( d \) = cylinders bore
- \( nc \) = \( n \)° of cylinders
- \( e \) = eccentricity (\( = \frac{1}{2} \) stroke)
The simplest way to control displacement is that SAI employs in its “double displacement technology”. This type of control switches between two displacement positions: minimum and maximum. The motor has a pilot line PIL(c) that is used to switch a spool valve.

When there is no pressure in the pilot line, the valve maintains (or changes it into) maximum displacement feeding the chamber on the left of the schematic diagram. When the pressure in the pilot line is between 20 and 30 bar, the valve shifts the spool, thus feeding the opposite chamber and, changing the displacement to minimum (=minimum stroke).

The crankshaft eccentricity moves from maximum to minimum (and back), enabling the motor to switch displacement whilst running with no shock to the system.

The valves in the scheme are integral with the motor.
METHOD 2: SAI KIT WITH ELECTRONIC CONTROL AND DIRECT FEED-BACK OF THE DISPLACEMENT

The electronic control actuates an electroproportional valve with a PID control based on a signal from the user (displacement request) with feedback from the motor (measured displacement).
METHOD 2: SAI KIT WITH ELECTRONIC CONTROL AND DIRECT FEED-BACK OF THE DISPLACEMENT

1. Electroproportional valve driven by the controller
2. Angular sensor, used to measure the oscillation angle of the cylinders
3. Electronic controller, calculating the signal from the position of the potentiometer and from the angular sensors
4. Potentiometer. This allows the user to set the required displacement.

The control logic used by the CPU is of proportional-integral-derivative type (PID).

The software loaded into the controller, solves (with a high frequency) the triangle determining the eccentricity. The calculated eccentricity defines the actual motor displacement, which is continuously compared (by the controller) with the displacement requested by the user (through the potentiometer).

Compactness → electrohydraulic controls integrated into the motor
METHOD 3: CONTINUOUS VARIATION WITH INDIRECT FEED-BACK MADE BY THE CUSTOMER

Another method, is a proportional control without feedback, using the minimum and maximum displacement lines. When high pressure (the pressure feeding the motor) reaches the “maximum displacement” inlet, with the other inlet discharging to tank, the displacement increases and it decreases if the high pressure reaches the “minimum displacement” inlet, with other to tank.

If the control of the change between the piloting of the ”maximum” and the “minimum” displacement is sensitive enough, this system allows the motor to be also used in any intermediate position. The control valve and displacement sensors are not included.

A client control system can measure, for instance, the speed and could compare it with the required value and then increase (or decrease) the displacement if the speed is higher (or lower) than that required.
METHOD 4: CP (CONSTANT PRESSURE) VALVE

The final method of displacement variation is the "CP valve". It is a device that allows the user to set a desired pressure value and then automatically adjusts the displacement of the motor. When the external load (resisting torque) is low, the motor reaches the minimum displacement, whereas as the load increases, the displacement also increases. The system has an "override port" (highlighted with the red arrow) which pilots to maximum displacement when a high pressure "signal" is received.
The desired pressure is easily set by turning the “setting screw”.

**METHOD 4: CP (CONSTANT PRESSURE) VALVE**

![Diagram of a motor and valve system](image)

Theoretical set pressure

- **Graph Details**
  - **X-axis**: Height of set bolt [mm]
  - **Y-axis**: Set pressure [bar] and [MPa]

- **Graph Data**
  - Theoretical set pressure is indicated by a straight line on the graph.

**Note**: The specific values and ranges on the graph are not detailed here but are clearly marked on the diagram. For precise data, refer to the graph in the document.
A CP valve system, when working in combination with a fixed displacement pump, becomes a “Constant Power” system.
Variable displacement axial piston motors, vary the displacement by changing the angle between the two axes. If the motor is used at less than 20-30% of the maximum displacement, the angles on which the forces are applied become extremely unfavourable and the overall efficiency drops. The axial component of the force is discharged as axial load on the bearings. Bent axis motors have a “minimum acceptable” ratio between displacements: $0.20 \leq \varepsilon_{\text{min}} \leq 0.25$

SAI variable displacement motors, vary their displacement by changing the torque arm. There is no big change in efficiency because the torque is generated with the same favourable angles in all displacement positions. The motors are able to supply high torque and high efficiency at very low speeds, so it is possible to use less mechanical reduction when compared with axial piston motors. SAI motors have a “minimum acceptable” ratio between displacements: $0.10 \leq \varepsilon_{\text{min}} \leq 0.20$
WHY IS THE SAI SOLUTION BETTER THAN AXIAL PISTON MOTORS?

APPLICATION EXAMPLES: MORE SPEED AND MORE TORQUE!!!

Rotary head with “bent axis” motor ($\varepsilon_{m_{\text{min}}} = 0.2$):
max power of 157 kW between 20÷100 rpm
with a Tmax of: 75 000 Nm.

Rotary head with SAI motor ($\varepsilon_{m_{\text{min}}} = 0.1$):
max power of 157 kW between 15÷150 rpm
with a Tmax of: 100 000 Nm.

Vehicle transmission with “bent axis” motor ($\varepsilon_{m_{\text{min}}} = 0.2$):
max power (per wheel) of 25 kW between 6÷30 km/h
with a Tmax of: 5 570 Nm

Vehicle transmission with SAI motor ($\varepsilon_{m_{\text{min}}} = 0.1$):
max power (per wheel) of 25 kW between 4÷40 km/h
with a Tmax of: 8 360 Nm.

Winch transmission with bent axis motor ($\varepsilon_{m_{\text{min}}} = 0.2$):
max power of 100 kW between 18÷90 m/min
with an Fmax of: 333 000 N

Winch transmission with SAI motor ($\varepsilon_{m_{\text{min}}} = 0.1$):
max power of 100 kW between 12÷120 m/min
with an Fmax of: 500 000 N.
Cam radial piston motors, vary the displacement by changing the number of active cylinders. This requires the control of two (or more) separate circuits into the motor. The number of possible displacements is always limited and the motor cannot have a continuous variation of displacement.

The variable displacement version allows the SAI motor to use any displacement between the minimum (which can be 0 cc/rev) and the maximum. Also, SAI dual displacement motors can vary their displacement while running with external load.

WHY IS THE SAI SOLUTION BETTER THAN THE CAM MOTORS?

BECAUSE CAM MOTORS DO NOT HAVE THE CONTINUOUSLY VARIABLE DISPLACEMENT !!!
• A motor which allows displacement variation brings important benefits to the customer: wide performance range coupled with high efficiency.

• The layout of the SAI motor allows many options for displacement control. No method is the “best one” in general, but each method has benefits that can make it the most recommendable solution for specific applications.

• The comparison with the products of the competition shows that the solutions offered by SAI each offer their own advantages: a very wide operating range with high efficiency, continuously variable displacement and smooth change of displacement while running.
For further information please get in contact with SAI’s Sales Department.

Thank you for your kind attention!