

DESIGN OF A NEW OIL DISTRIBUTION SYSTEM FOR THE NEW BOOSTER EK AND TK KICKER GENERATORS

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Scope

The HT Pulse generators are filled with oil to isolate the high potentials on some components inside. A flow through the system is necessary to evacuate the heat dissipated by the generator. Because of its influence on electronic components, we have to keep the temperature as stable as possible.

The generators will be located in the PSB BCER (Bldg 361). This location requires complementary measures against noise and leaks. There will be 3 generators at one extremity for the Transfer Kickers (TK) and 4 at the other extremity for the Ejection Kickers (EK). Each generator consists of a dump switch (DS) and a main switch (MS). The MS has only 1 oil compartment, the DS 3: Thyatron cage, resistor cage and RC cage.

Functions of the system

- ⇒ The installation must allow the filling, emptying and purging of the generators.
- ⇒ A reservoir has to have sufficient storage capacity for the cases where one or more generators are drained. During normal running a minimum oil volume is required to have a good separation of air bubbles and foam.
- ⇒ The system has to be protected against high pressures inside the switches not to cause leaks or other damage.
- ⇒ As in all oil systems it is necessary to control the oil flow and provide an interlock that shuts off the generator whenever flow is below a predetermined level.
- ⇒ During the filling of a generator, vacuum has to be applied to remove the trapped air as much as possible. This might require to interrupt or slow down the filling of the compartments for a while to give the oil the time to “defoam”.
- ⇒ To retain optimal oil insulation qualities as much as possible continuous filtering and desiccation must be provided.
- ⇒ During long shutdowns, a shut-off valve prevents the oil from leaking slowly back from the generators to the reservoir.

Definition of flow and temperature rates

The detailed results of the measurements and related calculation results made on the PSB dump prototype in building 174 can be found in excel file “010m0100.xls”.

The theoretical flow required to maintain the switch at a safe operating temperature can be calculated very easily.

$$W = Q = m.c.\Delta T$$

$$\Leftrightarrow P = q_m.c.\Delta T$$

$$\Leftrightarrow q_m = \frac{P}{c \cdot \Delta T}$$

$$\Leftrightarrow q_v = \frac{P}{c \cdot \Delta T} \cdot \frac{1}{\rho}$$

where: q_m : mass flow [kg/s]
 q_v : volume flow [m³/s]
 c : specific heat capacity of the oil [kJ/kg.K]
 ΔT : temperature-rise [K]
 P : dissipated power (heat) [W]

This would mean for 1 kilowatt and an acceptable ΔT of 10°C a flow (q_v) of 3.60 l/min

First test

A first test was carried out to match the theory to the real environment.

Measurements:

pressure drop: 0.6 bar

flow: 0.5 l/min - temp in 18°C - temp out 36°C

The measured flow rate was very poor, only 0,5 liters per minute is less than what one would expect.

The dissipated power in the system is approximately 800 W (calculated from the electric data). At this very low flow, the expected output temperature is 75°C, the 36°C is even to be considered low. This relatively low temperature is due to the cooling effect of the ambient air (16.8°C) on the large aluminum surfaces of the generator. Any rise of the ambient temperature would considerably reduce the cooling by dissipation to the ambient atmosphere. The resulting maximum temperature will rise even higher.

The flow will have to be higher than the 1 l/min because the measured output temperature is excessively high for the electronics inside the generator.

The differential pressure (Δp) of 0.6 bar is due to a high pressure drop in the many quick couplings actually installed on the generator limiting the flow to 0.5 liter per minute at the given pump pressure.

Conclusions:

For the definitive pump installation the quick couplings will be eliminated. The new flow at the given pressure will then be sufficient to provide enough cooling for the generator.

Before the system can be designed a new test without the quick couplings is necessary to determinate their real importance.

Second test

Circumstances:

All *Staubli* quick coupling connections have been removed, the distribution is via a massive 1/2" oil distribution block. Reductions from 1/2" to 1/4" remain unavoidable because of the (too) small openings on the generator's components.

The generator is completely cold (20°C), thus the oil viscosity is higher than in the first test.

Measurements:

The total system connected gives a flow of 3.80 l/min at a Δp of 0.062 bar (result after having compensated the hydrostatic pressure).

Conclusion:

If we want a flow of 10 l/min, the pressure will have to be at least 0.16 bar, calculated from the averages and assuming a linear increase of flow with pressure. In reality a non linear change with a smaller resulting flow has to be expected.

Since the pressure allowed in the switch housings is limited for the switch parts and because we want to use as much of this pressure for getting the oil through the switch, additional pressure drops after the switch have to be kept minimal.

We have to reduce:

1. The pressure drop in the return line caused by the flow resistance.
2. The hydrostatic pressure resulting from the height difference between reservoir and switch.

There was an important difference between the DS and MS flows. This is due to the nearly 6m long connecting PVC hose that feeds the MS from the distributor that is mounted near the DS. We neglect this since the hoses will be replaced by wider tubes for the final construction.

Resumed:

- The thyratrons produce most of the heat and thus require the biggest flow. A double entry and exit could increase the flow.
- If 0.5 bar is considered as the maximum for the switch, we should keep 2 points in mind:
 1. keep the return lines as short and as wide as possible;
 2. install the (return) reservoir lower than the switch itself.

Pump definition

The pump will feed 3 generators in parallel for the TK and 4 for the EK the additional pressure losses in the tubing and filter will be more important than the generators themselves. Each generator takes about 10 l/min.

total flow: 30 l/min and 40 l/min approximately
pressure: 0.16 bar + additional pressure 1 bar minimal

The existing hydraulic units

As in FAK, Lear, AA,...

Almost all systems consist of 2 reservoirs; one main and one slave reservoir. The main reservoir contains the main pump and the oil necessary for normal operation. The slave reservoir is just there to contain the oil if it is drained from the switches. Usually, a separate purge pump and a pump for refilling are used for this purpose. Each reservoir is equipped with a silicagel dessicator and float switches to protect the pumps against running dry and to protect against overfilling.

All the system pumps are volumetric pumps which have been over-dimensioned. Because the pressure of volumetric pumps rises up to very high values when their

flow is restricted, they can break or cause damage to connected equipment. A safety valve is necessary to by-pass the flow when a certain pressure (about 6 bar) is reached. The presence of a manual by-pass valve and a set of adjustable distribution valves makes adaptation of the pump system to any connected system possible. This manual regulation can cause the by-pass valve to be solicited continuously.

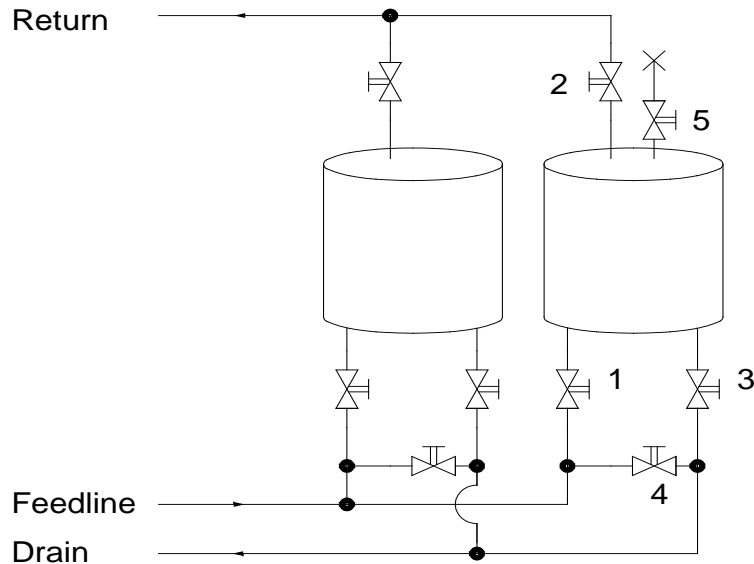


Figure 1: design with 3 separate valves per switch

The distribution units have flow meters (Brooks rotameters) to visualize the flow distribution over several groups of switches.

Each switch has a set of valves and a vacuum flange to make normal operation and maintenance interventions that require emptying possible

1. Manually adjustable valve for intake
2. Manually adjustable valve for outlet
3. Manually adjustable valve for drain
4. Manually adjustable valve for bypassing inlet / outlet valves.
5. Vacuum shut-off valve with flange for connecting a vacuum hose.

The new design

Pumps

For the reasons stated in the section “The existing hydraulic units” on page 3, I did not take a volumetric pump as before.

To choose the most suitable pump from the offers of several suppliers, the characteristic of the generator was determined first and put together with the pump diagrams of all the proposed pumps on a pressure chart. For all the details, see page 1 of this paper. As one can see it is necessary to correct the given water pressure line for the pump with the specifications of the oil (density and viscosity).

The operating point of the system will in this case be 36 l/min at 0.15 bar with the four generators open. If one or more switches are disconnected, the operating point will move to 28, 22, 12 or 0 l/min, the pressure never exceeds 0.27 bar!

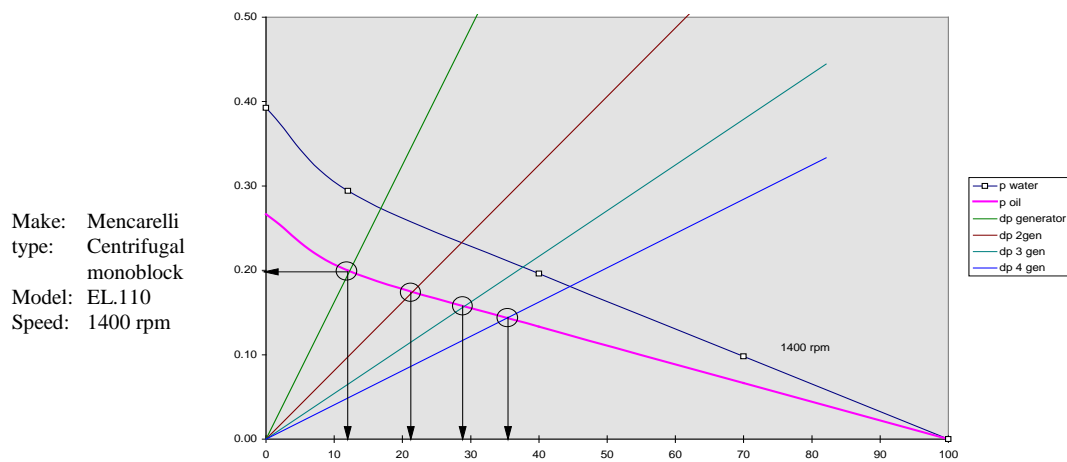


Figure 2: pressure chart

Noise

The spindle pumps that were used previously produce a lot of noise. The reason is that Diala oil has a relatively low viscosity (32,8 cSt). The proposed centrifugal Pumps only produce a fraction of this noise since there are no moving parts in contact anymore.

Noise reduction is *very important* because the system will be installed in the much frequented BCER.

Reservoir

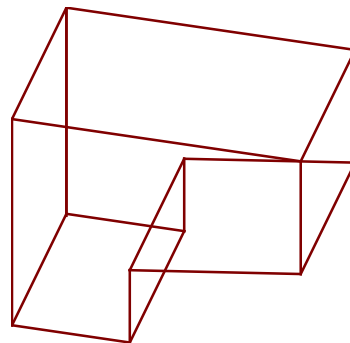


Figure 3: Reservoir

With an adapted shape, 1 tank instead of 2 could be used. It can have a large surface (and volume) in the upper half and a much smaller surface in the lower half. When running normally, the oil level is high enough to separate foam effectively though there is enough room above it if required.

Advantages:

- reduced space requirement and cost.
- extra pump or solenoid for the oil transfer to the main tank
- level switches and control of the pump
- one desiccator

- reduced piping hence less susceptible to leakage.

Valves

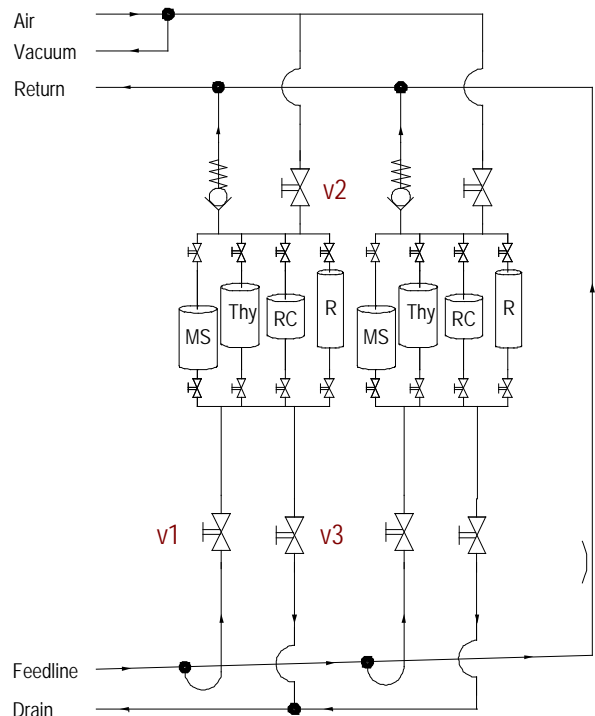


Figure 4: new setup

In order to reduce the risk of manipulation errors three shut-off valves and one spring load non-return valve are installed on each switch instead of the 3 adjustable valves and the vacuum shutoff valve as on the old system. Care has still to be taken not to pump oil through the purge valve (v2). Fewer false operations remain likely than with the previous system.

A spring loaded valve replaces the usual shut-off valve on the outlet. The usual hand-operated valve causes problems if it is not opened and closed at the precise moment. If during filling, the valve is opened too early at the end of the vacuum- it causes a back-sucking of oil and air in the generator, undoing all the care of purging before. Opening it too late provokes an over-pressure in the generator. The non-return valve can not let anything flow back towards the generator but will always open from the least over-pressure.

Operation becomes easier. Five combinations are necessary for the operation: They are obtained with the 3 valves v1, v2 and v3 and by connecting the purge to vacuum or by connecting the same line to the atmospheric pressure to let air into the switch compartments during draining.

Feedline v1	Purge v2		Drain v3	Function
open	closed		closed	Run normally
closed	open	to air	open	Drain
open	open	to vac.	closed	Fill + Purge
closed	open	to vac.	closed	Purge, pause filling
closed	closed		closed	Stop

Flow adjustments are no longer required because the pump and the system are matched. All the operator has to do is turn the valves 90 degrees.

The system automatically avoids air ingress in the switches or to accumulate in front of closed valves during shutdowns. The oil take-offs on the main feed line are made on the bottom. The feedline itself has a little slope and at the upper end, a passage of restricted section avoids accumulation of air.

Because of these measures and the choice of a convenient pump (pressure) diagram local by-pass valves can be eliminated.

Temperature control

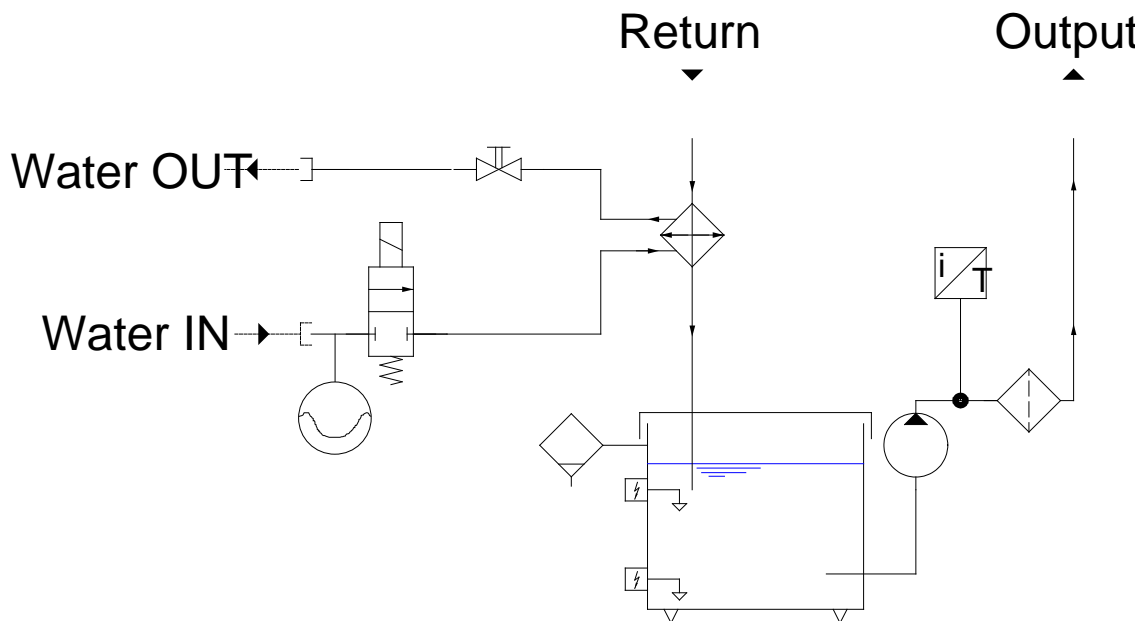


Figure 5: Temperature control

Instead of using an in-line heat exchanger and a servo valve, the cooler is placed in the return line and the servo-valve is replaced by a solenoid operating in PPM.

Advantage:

- ☺ saving of 800 CHF on the non-required servo valve
- ☺ the temperature changes are smoother since the total oil mass is damping the temperature shocks.

Disadvantage:

- ☹ A small accumulator has to be used to damp the hydraulic shocks (“water hammer”) in the feedline.

The shut-off valve had to be pneumatically operated since impurities in the water disturb the function of servo-solenoid valves. These valves also offer the possibility to adjust their opening and closing speeds to reduce the "coup de bélier" effect in that way.

Design Study of a fully Automatic Distribution System

Purpose

An oil distribution system, which can be operated by simple instructions by means of a menu, guided operator console with the possibility of a remote control via a serial connection to the controls.

Reduction of the intervention time necessary for purging, draining the switches and checking oil levels, before the real intervention on the switch components themselves. Easier operation, no longer 40 valves from which to choose, but a few choices such as “empty DS 2” or “fill DS 4”

Hydraulic diagrams

Drawing PS-KM-D-00-100-3 as a first design

Drawing PS-KM-D-00-102-3 as the further evolution of it

Explanation

The numbers relate to the design drawing PS-KM-M10-345-3 , **see Annex 1**, the final layout can be consulted on AutoCAD drawings.

1. There is a system drain valve to empty the reservoir using the system's own pump as well as...
2. A system fill valve to pump oil in the main reservoir from a barrel.
3. It is necessary to have a shut-off valve for maintenance on pump and filter as well as during long shutdowns to prevent back leaking from the generators to the reservoir.
4. Level switches (or level sensor, see 31) mounted on master reservoir.
5. Desiccator to help keep the oil dry.
6. Oil reservoir in mild steel.
7. Heat exchanger to cool the oil with cold water.
8. Pneumatic valve for Pulse-Pause Modulation of the water flow to the cooler. For further information, see page 7 "Temperature control".
9. Needle valve for the adjustment of the proportional band (PB) of the water cooling loop. It is adjusted in a way to have the maximum required water flow necessary if the solenoid (8) stays open continuously.
10. Flow transmitter mounted on each individual component of the generator to monitor the cooling and related isolation of all parts.
11. Four hand operated spherical valves allow the isolation of complete switch components. If maintenance has to be carried out on a part of the generator which is for 95% the case, one can avoid the drainage and purging procedure on all the rest of the generator.
12. Compressed air conditioning unit with 10µm air filter.
13. Intake shut-off valve for the generator (over-pressure always at pump side).

14. Normally open outlet valve for the generator.
15. Non-return valve at outlet.
16. To pump out air for purging and allow air in for draining a motorized shut-off valve or small size two-way solenoid on the purge opening is necessary. But it will have to be tight at differential pressures in both ways. E.g. normal running: over pressure in tank and vacuum held in generator while separation tank is emptied at atmospheric pressure.
17. Shut-off valve on oil drain. In the closed position this valve has to resist to differential pressures in both ways (vacuum and over pressure) and thus a solenoid is mostly not suitable, more because the orifice has to be large enough to drain the system in a reasonable time. The best valves offering both tightness in two directions and a large opening are pneumatically operated.
18. -
19. Vacuum shut-off valve between vacuum pump and separator reservoir.
20. When the oil separation tank has to be pressurized to empty, compressed air is fed through this solenoid. By the same way air has to pass into the generators whenever they are emptied.
21. Vacuum pump for filling (purging) under vacuum in a way to eliminate air pockets in the HT isolating oil. The same pump is also used to purge the SF6 distribution system (not in the scope of this paper).
22. Oil separation tank.
23. In case of very poor flow demand trough the generators, the system can pump oil through a bypass valve. This reduces accumulation of air pockets in the feed lines.
24. Set of level switches to control the amount of oil deposit in the separation tank. This is essential to protect the vacuum pump against sucking oil.
25. To avoid that the vacuum in the oil separation tank pulls oil and air back from the drainpipe to which it is connected a non-return valve is essential in the drain of the oil separation tank.
26. Optical detectors make the difference between oil and air in the purge and drain collectors, enabling the system to detect the end of draining and filling procedures.
27. 10 µm oil Filter.
28. Temperature transmitter.
29. Main pump for oil circulation and draining of the main tank.
30. A pressure transmitter is interesting for diagnosis and system information and protection.

The generator outlet valve is the only normally open valve. This guarantees the safest state in case of a complete power failure. In absence of electric power, the oil and water circulation is stopped and the reservoir is sealed but the return from generator to reservoir opens to release residual pressure in the generator.

Operation

Manipulations

The handling consists of 5 modes:

1. Run (en marche):

In the normal run mode, the oil circulates freely through all generators. The inlet

valve is open, drain and purge valves remain closed. Only in this mode the oil interlock relay is ON and the generators can be operated.

2. Standby (prêt):

Generators filled and the valves closed to keep the oil in the generators. The pump may be stopped,

3. Draining (se vide):

To empty the selected generator(s). The inlet closes, and the drain valve opens. To push the oil out of the generator, the purge valve opens together with the air valve that lets over pressure into the oil separation tank.

The oil can keep circulating through the remaining generators if required. To stop the circulation pump the operator can select “Stop” at any time, then all valves of the non-drained generators close before the pump stops.

Drained generators can only return to “Run” through the Fill-mode.

4. Filling (se rempli):

The drain and air valves close, the vacuum pump is started. The previously emptied generators are put under vacuum to evacuate the air and then filled with oil again. Timer functions have to help this process. When filling is completed, the normal run mode follows automatically. The vacuum pump continues to pump as long as possible. Once the oil level becomes too high the valve has to isolate it from the incoming oil.

5. Pause filling/Pause Draining:

To make manual "defoaming" possible a pause/resume button will be mounted on each generator to remove oil vapor. During such a pause the vacuum is maintained but the oil admission is shut off. This gives the air the time to get out of the system. The same function can be used while draining to let the oil sink to the bottom.

For the drain and fill procedure it is possible to isolate a part of the generator (e.g. the resistor cage, the thyatron cage) by means of the manually operated ball valves on the inlet and outlet of each part. Limit switches can be installed on these valves in a way to prevent accidental operation in “normal run mode” with these valves closed.

Remote readout of all gauges over the ethernet can be implemented for surveillance.

See Annex 2 for the menu structure

Automatic functions

- Draining the oil separation tank and protecting the vacuum pump against intrusion of oil.
- Cooling the oil (PID regulator).
- Monitoring of flows, temperature and pressure.
- Timer delayed interlocks for flow of each generator. (a short interruption does not need to stop the generators (hardware interlocks still have to be provided).
- Temperature interlock.
- Counting of working hours for preventive filter replacements.
- After power cut everything returns automatically to its previous state.
- Pumping oil in/out of the system through a service plug when requested.

Instrumentation

Feedback for the controlling PLC comes from 3 types of sensors.

Temperature and pressure sensors

At least one temperature probe is needed for the oil temperature regulation system. One pressure sensor helps for the diagnostics on the system.

Level indicators

Mechanical or capacitive level switches are used in the reservoirs.

Optic detectors are installed in the drain and purge collectors in order to give the PLC feedback about the fluid coming out of the generator while draining or purging. Only the optic "level" switches are fast and small enough to be installed at those points.

They can even detect a single drop. The software filters the information to recognize full and empty states and puts draining and filling in standby when necessary.

Flow Transmitters

Since all generator components are working in parallel it is necessary to survey the flow in each component (4 per generator). This big quantity requires a small and inexpensive sensor.

The insensitivity of the sensor for the location in the tube system is also important. If a long straight section is required it complicates the installation. Finally, turbine type meters with a pulse output were connected to a multiplexed counter, controlled by the system's PLC.

ANNEX 1 Hydraulic diagram

Annex 2 Structure of Operation Menus

Distribution

Kicker Magnets Section

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B. Dumas

M. Hourican

Jean-Pierre Riunaud