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DISTRIBUTED PUMPING BY NON-EVAPORABLE GETTERS IN PARTICLE ACCELERATORS

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SUMMARY

Distributed pumping in particle accelerators has recently been proposed as an interesting approach to maximize the pumping efficiency inside the chambers. The distributed pumping can mainly be performed by ion pumping structures or by non-evaporable getter devices arranged along the inner walls of the chambers.
The non evaporable getter approach, which appears to have very promising technical and economical impact, is considered and discussed. In particular reference is made to the use of non-magnetic strip coated with both high temperature (700-800°C) activatable getter materials and low temperature (less than 500°C) activatable getter materials of more recent development.
The sorption characteristics of these getter coated strips are reported for the most important gases after efficient activation. The results show the possibility of attaining high "linear" pumping speeds, ie. as high as a few hundred liters per second per meter of chamber length for hydrogen.
The suitable modes of operation of the getter coated strips for this specific application are also discussed together with the preliminary results of the practical embodiment of this approach.

1. INTRODUCTION

In recent years, to overcome the economical and technical problems in pumping particle accelerators of increasing dimensions, the concept of "distributed" pumping has been introduced. This distributed pumping can be based on "integrated" sputter-ion pumps (1, 2, 3, 4) and/or on "linear" non-evaporable getter pumps (5, 6). This latter approach serves to have an interesting economic and technical impact together with flexibility of operation as it is not affected by magnetic cycles. It can also be operated without power supply after activation of the getter material, can be used as a heat source for in-situ bake-out, etc. In view of the potential of this approach in pumping particle accelerators, further information and the more recent developments of the getter materials suitable for this application, are described and discussed.

2. STRUCTUBRE OF THE LINEAR GETTER PUMP

The linear getter pumps are based on the use of portions of non-magnetic metallic strips (constantan) coated with powder of a getter alloy (7). Suitable lengths of the above strip can be arranged directly in each sector of the beam chambers. An example of such an arrangement (6) is shown in fig. 1. If a side chamber is available, this can be used to host the getter strip. As room is available in this case, a suitable support frame can be arranged to allow for a more uniform pumping on both sides of the getter strips. Activation (and when necessary operation) of the linear pump is obtained by heating the getter strip with direct passage of current; this implies the use of electric insulation means and guides to take care of the thermal expansion (as in fig. 1).

Of course, the actual practical arrangement is to be studied in connection with the specific characteristics of the particle accelerator considered.

3. FEATURES OF THE GETTER STRIP

3.1 Physical characteristics and operation conditions

A getter alloy which can be proposed and has already been used, thus far, (5, 6) in this application is a Zr-Al alloy (commercially known as St 101) (8). An efficient activation of this alloy is obtained when, for example, it is heated under vacuum (better than about 10^{-4} torr) at 700°C for 45 minutes. Higher temperatures can be used with shorter times, but generally they are not advisable because of the higher thermal loads involved, larger current necessary etc.; lower temperatures are also possible with larger times, but, eventually, drastic decrease in the gettering efficiency takes place (9). The activation temperature can be selected depending on the permissable thermal load on the walls of the chamber.
However a "pulsed" activation can also be proposed to avoid excessive heating of the chamber walls.
According to this procedure, the getter strip could be repeatedly heated to the activation temperature for some time and there allowed to cool down to prevent the walls from exceeding a given temperature; this procedure is terminated when the overall time at the activation temperature equals that forseen for continuous heating at this activation temperature.
In some cases, however, even the selection of somewhat more moderate activation temperatures or the use of "pulsed" activation may be a problem and only drastically lower activation temperatures, e.g., 500°C or less, may be tolerated. In this condition the Zr-Al alloy exhibits a drastic decrease of gettering efficiency. A recently developed Zr-V-Fe alloy (known as St 707) (10) may then be considered for this application. This ternary alloy can, in fact, be activated at 450 ∓ 50 °C without drastically sacrificing its gettering efficiency as it will be seen later.
Both Zr-Al and Zr-V-Fe can be operated at room temperature, after activation, when pressures are in the range of less than about 1.10^{-7} torr and gas loads are not large; when large gas loads are involved, as during bake-out, the operation temperature is preferably around 400°C and 280°C, for St 101 and St 707 getter strips, respectively.
The main physical characteristics of both St 101 and St 707 getter strips are summarized in table 1.

3.2 Sorption characteristics

Sorption tests have been performed on getter strips in different conditions and the results are shown in tables 2 and 3, both for Zr-Al and Zr-V-Fe getter strips. The gases considered were H_2 and CO as two important gases in the residual atmosphere of particle accelerators. From the tables it is seen that St 101 getter strip has an excellent sorption efficiency

at standard activation but is much more sensitive to the activation temperature than St 707 getter strip with drasting decrease in sorption characteristics if activation is performed at 500°C for 45 minutes.
The sorption capacity for H_2 is determined by the equilibrium pressure of this gas according to the Sieverts law found for the H_2 - getter material system (10). The two sorption temperatures higher than room temperature have therefore been selected to have the same H_2 equilibrium pressure, at the same concentration, for the two getter materials (400°C for St 101 and 280°C for St 707). The equilibrium pressure of H_2 in Zr-Al alloy is about 2 orders of magnitude less than in Zr-V-Fe alloy (10): the absolute value of H_2 equilibrium pressure with this latter alloy is still very low, at room temperature, at relatively large H_2 concentration and allows its use in the range of UHV as necessary in this application.
The sorption speeds have been given at 3.10^{-5} torr, which is a relatively high pressure in normal operation of particle accelerators, but may be reached during baking. If lower pressures are considered, no variation in sorption speed is to be expected for H_2, which has been found independent of pressure in a wide range (7, 11). During the present tests with Zr-Al alloy the sorption speed for CO at 400°C, was found to increase with decreasing pressure down to about a few 10^{-7} torr and then it levels off; as shown in fig. 2. Similar results are expected from initial tests of the same type in St 707 getter strips which are in progress. This can possibly be explained by considering the getter material to "digest" the CO sorbed molecules, by diffusion, more easily when their rate of arrival is lower, until a balance is reached.
The values of capacity reported in the tables refer to the quantity of gas that can be sorbed after on activation. This quantity, in general, may be sufficient for long periods of operation in UHV conditions. The total capacity for active gases of the getter is however much larger; it can be exploited by further activations when is necessary, e.g., after air exposures or under very large gas loads (12); for H_2 the limit may only be the embrittlement limit (very large concentrations are however involved: 600 cm^3 torr/cm^2 or the active gas impurity level present in it (9).

3.3 Pumping performances of a linear getter pump

If a linear pump is considered with a getter strip of 30 mm width the practical available getter coated surface is approximately 500 cm^2 per meter. If, for example, reference is made to H_2 as the gas to be sorbed then using the data reported in the previous section the maximum pumping speed per meter can be evaluated as follows (assuming both sides of the getter strip equally available for pumping):

a) operating in the low pressure region (10^{-7} torr) and therefore preferably at room temperature
   - St 101 getter strip (activated at 700°C x 45') speed = 500 l/sec
   - St 707 getter strip (activated at 500°C x 45') speed = 300 l/sec

b) operating in the relatively high pressure region (10^{-7} torr) and therefore preferably at higher temperatures than 25°C.
   - St 101 getter strip (activated at 700°C x 45' and operated at 400°C) speed = 700 l/sec
   - St 707 getter strip (activated at 500°C x 45' and operated at 280°C) speed = 350 l/sec.

In all cases these values seem to be high in comparison to those obtainable with other pumping means.
The sorption capacity per meter of linear pump would be about 70 torr . l for H_2 and 0.1 torr . l for CO, for a pump operating at 25°C, which is expected to be the more usual working temperature of the accelerator chamber after baking. Assuming degassing rates of about 2.10^{-12} torr l/sec.cm^2 (6), mainly H_2, it is seen that several years of operation might be expected without the necessity of re-activation and with the possibility of maintaineing UHV conditions. In practical tests with linear non-evaporable getter pumps (5, 6) these expected conditions seem to have already been confirmed.
In addition to the presently reported data and the above mentioned practical results with linear getter pumps in simulation chambers, some recent preliminary tests conducted both in stainless steel and aluminium chambers, at CERN (13) also indicate that a linear St 101 getter pump working with very small additional pumping (ion-and turbo pumps) can reach the range of 10^{-11} torr in relatively short times (about 8 hours); this result is attained provided the vacuum chamber is allowed to reach at least 120°C during activation of the getter strip which is therefore performing an in-situ bake-out.

4. CONCLUSIONS

The use of linear getter pumps appears to provide an interesting and practical contribution to accelerator pumping techniques, a view point supported by preliminary experimental results. The Zr-Al getter strip, thus far more extensively investigated, exhibits very good sorption characteristics when its activation with practical times involved is possible at temperatures higher than 500°C; if relatively low activation temperatures are necessary preliminary result show interesting possibilities for the application of a special Zr-V-Fe getter material.

5. ACKNOWLEDGEMENTS

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Captions to figures:

Fig. 1 Sketch of arrangement of a getter strip in an accelerator chamber

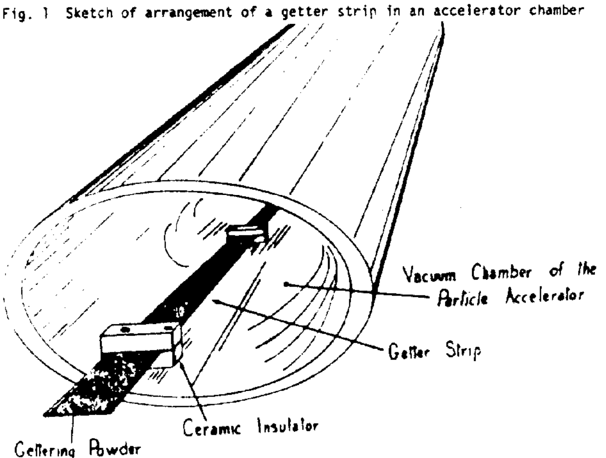

Fig. 2 Specific sorption speed for CO with Zr-Al getter strip at 400°C, after activation at 700°C for 45', as a function of pressure.

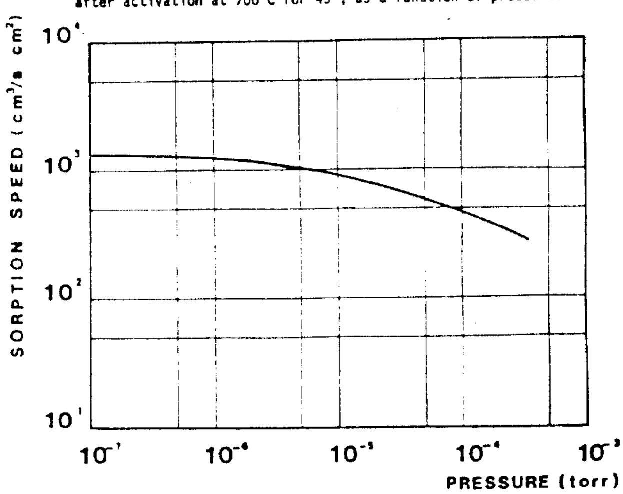

TABLE 1 - PHYSICAL CHARACTERISTICS OF GETTER STRIPS

SUBSTRATE MATERIAL	CONSTANTAN
WIDTH	30 MM *
THICKNESS OF SUBSTRATE	0.2 MM (OR 0.4 MM)
AVERAGE QUANTITY OF GETTER POWDER PER CM^2	30 MG
EXPANSION COEFFICIENT	$14.9 \cdot 10^{-6}$ °C^{-1}
RESISTIVITY	49.10^{-6} OHM CM

INDICATIVE ELECTRIC PARAMETERS FOR ACTIVATION AT:		POWER (WATT/METER) **	CURRENT (A)
	700°C	1000	150
	500°C	700	95

* DIFFERENT WIDTH COULD BE AVAILABLE

** LOWER VALUES CAN BE NECESSARY DEPENDING ON THE SURROUNDINGS OF THE GETTER STRIP

TABLE 2 - SPECIFIC SORPTION CHARACTERISTICS OF St 101 GETTER STRIP (CM^3/S PER CM^2 OF GETTER COATED STRIP) AT DIFFERENT ACTIVATION AND SORPTION TEMPERATURES

GETTER STRIP	St 101							
SORPTION TEMPERATURE	25 °C				400 °C			
ACTIVATION CONDITIONS	500°C x 45'		700°C x 45'		500°C x 45'		700°C x 45'	
TEST GAS	H_2	CO	H_2	CO	H_2	CO	H_2	CO
INITIAL SORPTION SPEED * $CM^3/SEC. CM^2$	< 10	< 1	1000	300	200	< 1	1400	700
SORPTION CAPACITY ** CM^3 TORR / CM^2	-	-	150	0.2	100	-	100	10

* WHEN THE SORBED QUANTITY IS 10^{-2} CM^3 TORR / CM^2

** WHEN SORPTION SPEED HAS FALLEN TO 10% OF THE INITIAL VALUE CONSTANT PRESSURE ON GETTER $3 \cdot 10^{-5}$ TORR

TABLE 3 - SPECIFIC SORPTION CHARACTERISTICS OF ST 707 GETTER STRIP (CM^3/S PER CM^2 OF GETTER COATED STRIP) AT DIFFERENT ACTIVATION AND SORPTION TEMPERATURES

GETTER STRIP	St 707							
SORPTION TEMPERATURE	25 °C				280 °C			
ACTIVATION CONDITIONS	500°C x 45'		700°C x 45'		500°C x 45'		700°C x 45'	
TEST GAS	H_2	CO	H_2	CO	H_2	CO	H_2	CO
INITIAL SORPTION SPEED * $CM^3/SEC. CM^2$	600	50	600	60	700	120	800	400
SORPTION CAPACITY ** CM^3 TORR / CM^2	200	0.15	200	0.30	100	4	100	20

* WHEN THE SORBED QUANTITY IS 10^{-2} CM^3 TORR / CM^2

** WHEN SORPTION SPEED HAS FALLEN TO 10% OF THE INITIAL VALUE CONSTANT PRESSURE ON GETTER $3 \cdot 10^{-5}$ TORR