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Protection of Drift Chambers with Thin-Wall Tubes Operating in Vacuum against Vacuum Penetration

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1. Abstract. In the past years, drift chambers with thin-wall tubes (straws) operating in high vacuum (~10-5 mb) have become to be used in experimental studies of rare decays. Any drift tube of the operating chamber may suffer a mechanical or electrical damage and a subsequent leak. The complete failure of the tube is not excluded either.

To protect the chambers against the above damage, we have developed and tested a relatively simple protection system based on uniquely designed energy-independent devices. If air-tightness is broken and gas starts leaking from the tube into the vacuum, they automatically cut off the gas flow on both ends of the damaged tube and disconnect it from the gas supply.

2. Introduction. Recently, experiments on the study of rare decays have become carried out using drift chambers with thin-wall tubes (straws) located and operating in the vacuum channel of an experimental setup. This allows appreciably improving the reconstruction accuracy of particle coordinates. These chambers already operate in vacuum at the NA62 facility at CERN's SPS [1, 2]. In addition, there are a few projected experiments using drift chambers in vacuum at other charged-particle accelerators, see for example, experiments Mu2e, COMET, SHiP [3 - 5].

Though quality of tubes is very thoroughly checked during their manufacture and assembly, it is not excluded that any of them can suffer various kinds of damage, mechanical or electrical, and a subsequent leak while the chamber operates in vacuum, and a complete rupture is also possible. To protect the chamber as a whole in a case like this, it is necessary to prevent vacuum from penetrating through the damaged tube into other tubes . Note that tubes with thinner walls or larger diameter, if their use is needed, have a higher failure probability.

To this end, we propose that our designed unique energy-independent protection devices be mounted at the inlet and outlet of each drift tube (or group of tubes, see below). Under emergency, it automatically will shut off the damaged tube and he chamber will remain serviceable.

3. Protection system for a drift tube operating in vacuum. Figures 1 show the drawing and the view of our proposed protection device, and Fig. 2 depicts a simple protection system for one tube based on these devices.

Let us first consider the device in Fig. 1a. It consists of a vertically arranged body -1 with the inner cavity, which is shaped as the frustum of a cone with its large base down (unlike the rotameter!), and air-tight lower - 2 and upper 3 fittings with seats - 4 and - 5, also cone shaped, for the shutoff element. In addition, they serve to connect the device to the gas supply and the drift tube respectively. Along the generatrix of the cone in the lower fitting seat there are two or more grooves - 6 with the cross section calculated to be such as to allow the working gas flow freely to run through. The shutoff element is a ball - 7, which is kept by its own weight in its working position in the lower seat and forms together with the grooves the gas passage cross section.

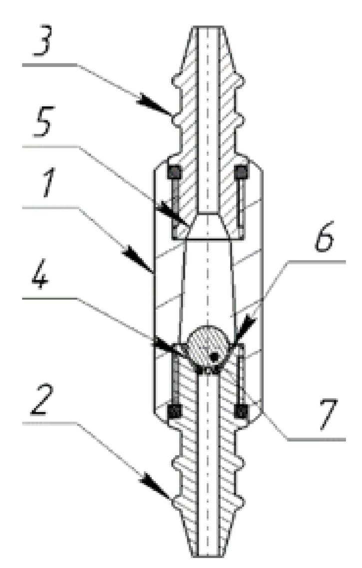


Fig. 1a

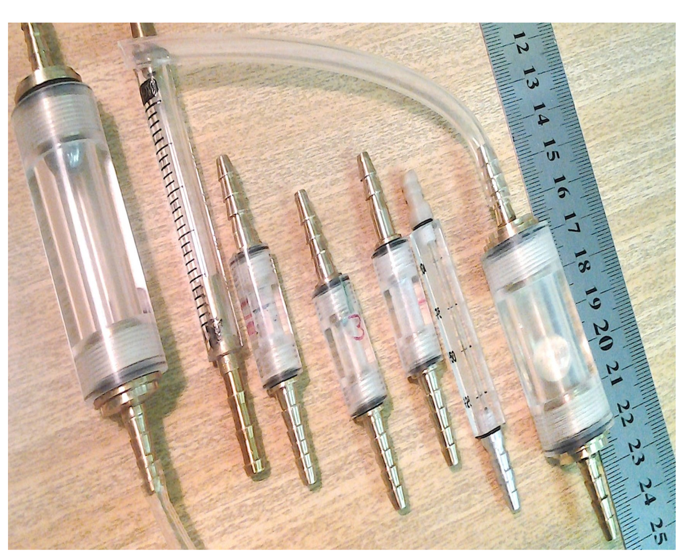


Fig. 1b.

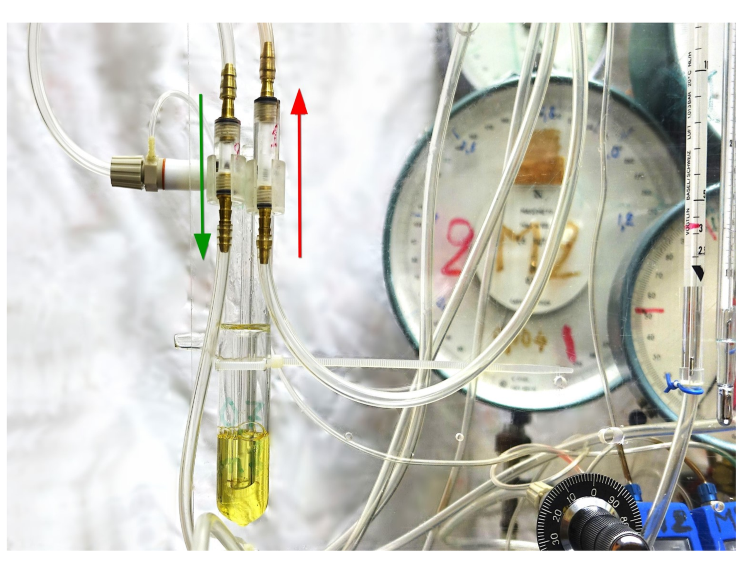


Fig. 1c

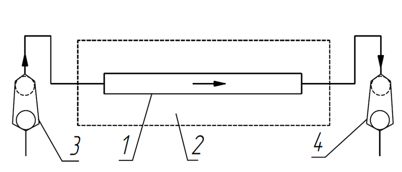


Fig. 2

Now let us proceed to the operation of the protection system in Fig. 2 for one drift tube in vacuum. Two vertically arranged identical devices are connected to it on two sides. Their upper fittings are connected to the ends of the tube, and the lower fittings are connected to the gas source and lead away respectively.

Therefore, under normal conditions both balls are kept by gravity in the seats of the lower fittings, and the gas freely runs through the tube.

In the case of tube damage and leak, the gas flow at the tube inlet increases beyond the rating value. The ball in the inlet device is shifted up into the lower part of the conical frustum. The gas passage cross section decreases, and thus the lifting force exerted on the ball increases. Therefore, it will find itself in the upper seat, cutting off the gas flow into the tube.

The direction of the gas flow at the other end of the tube begins reversing. Therefore, the reversed gas flow moves the ball in the outlet device up from the lower seat, closing the tube outlet. Consequently, the tube will be shut off both ends.

The working gas flow and the tube emergency shutoff level depend on the size of the grooves that form the passage cross section together with the balls and on the weight of the balls.

3. The bench. To check the operation of the proposed system and clarify its operating conditions, we assembled a test bench shown in Fig. 3. Instead of the thin-wall drift tube, a duralumin tube with length 2000 mm and inner diameter 10 mm was used. A controlled gas flow was supplied from the rotameter to one end of the tube, while the other end of the tube was connected to the atmosphere through a bubbler.

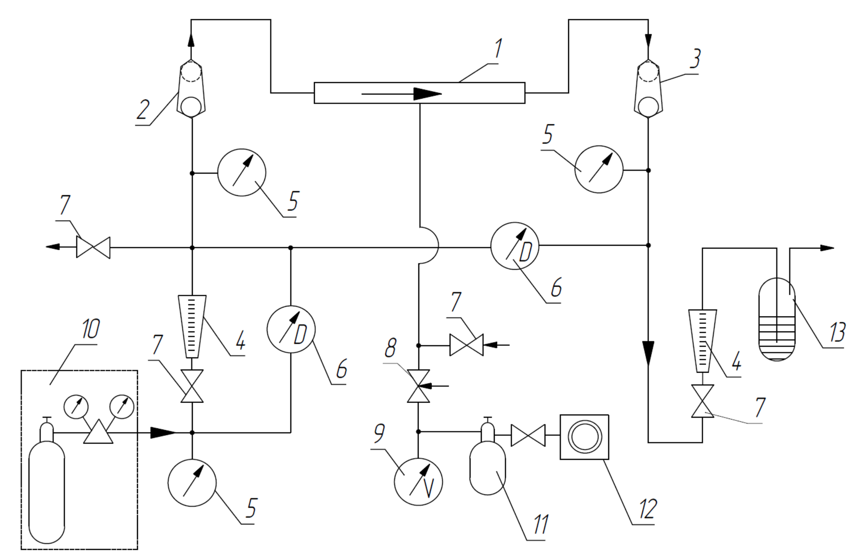
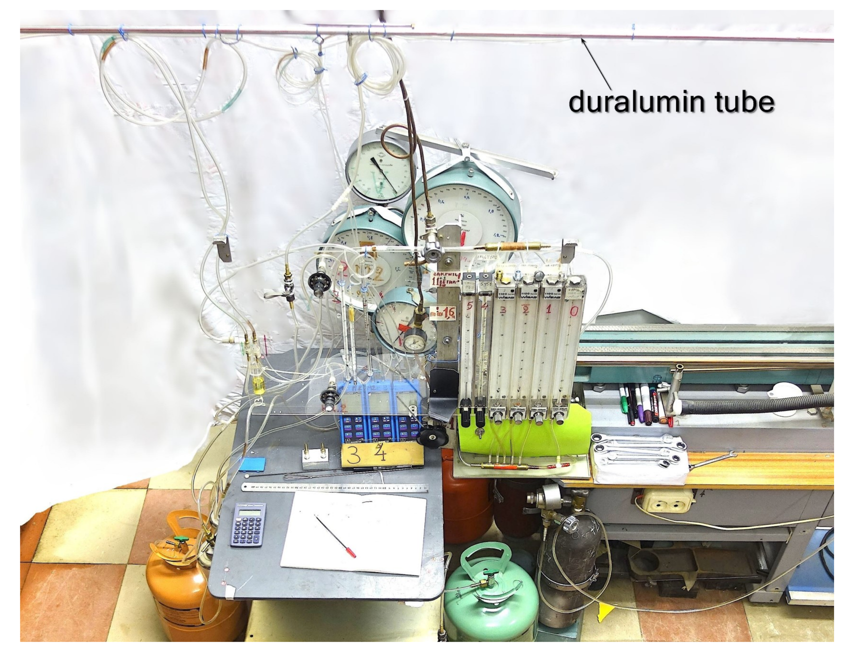


Fig. 3. Layout of the test bench for the protection system: 1 - duralumin tube, 2 - inlet device, 3 - outlet device,4 – rotameters, 5 - manometers, 6 - differential manometers, 7 - valves, 8 - needle valve, 9 – vacuum meter,10 – high pressure gas cylinder, 11 – fore cylinder, 12 – vacuum pump, 13 – bubbler.



A needle valve connected to the middle of the tube and, through the fore cylinder, to the vacuum system, allowed imitating a tube leak and its amount as desired. Ordinary and differential manometers were used to monitor pressure and its variation in the system.

The shutting elements were steel bearing balls 4.74 mm in diameter (weight 435 ± 0.3 mg) and plastic balls 4.72 mm in diameter (weight 65 ± 0.3 mg).

4. Results of measurements. The system of the protection devices has passed the tests. They showed that it allowed the gas to run freely within the given working flow limits and stably operated to shut both ends of the tube when the leak occurred. For devices with steel balls, the cutoff threshold turned out to be 80 nl/h. With lighter balls the cutoff threshold decreases to 30 nl/h.

The gas flow in the tube was varied from 5 to 80 nl/h at a step of 5 nl/h using a rotameter. The differential manometers measured the pressure difference at the rotameter and the protection system. The variation of these pressures as a function of the gas flow through the tube is shown in Fig. 4 a,b. Red curve shows variation in the differential manometer readings at the ends of the system, and blue curve shows the same at the rotameter. The curves are interrupted on approach to the cutoff threshold.

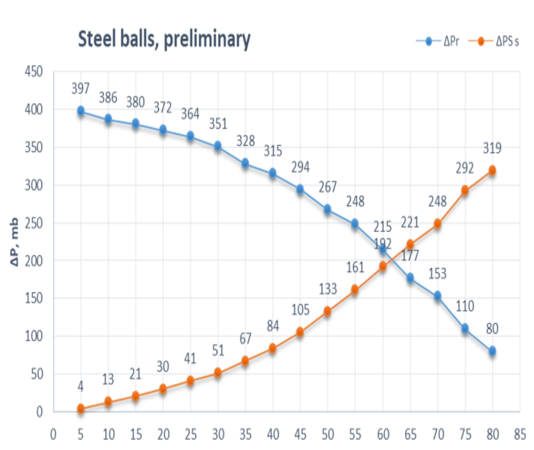


Fig. 4a

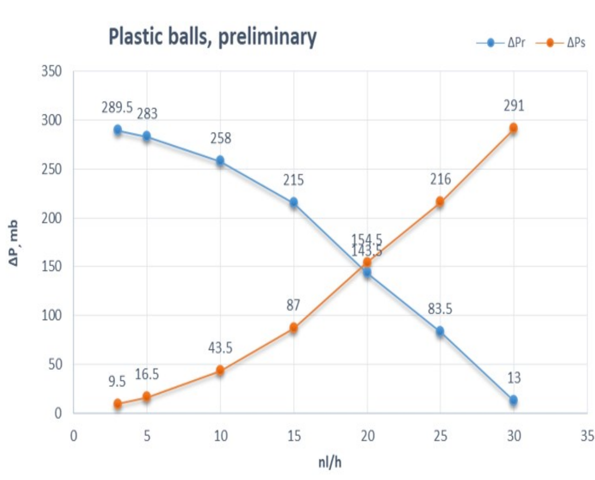
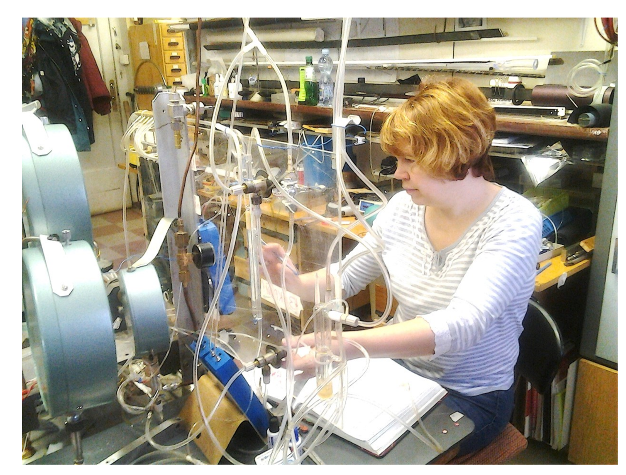


Fig. 4b



Since there is a lot of tubes in the chambers, their group protection can be considered for decreasing the number of devices and simplifying the protection system. The tubes can be grouped into twos, fours, eights, and other even numbers, being connected in parallel (Fig. 5a) or in series (Fig. 5b).

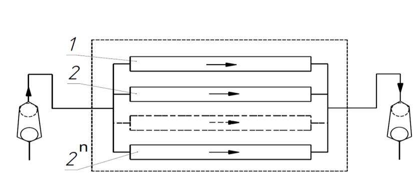


Fig. 5a

This will decrease the number of devices to be used, and the entire group of tubes will be disabled in the case of emergency.

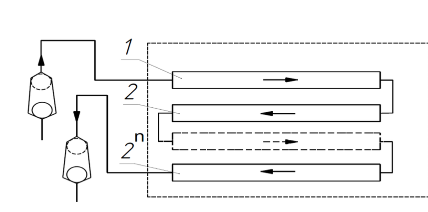


Fig. 5b

Conclusion. A system is proposed for protecting a drift chamber with thin-wall tubes operating in vacuum if any of its tubes is damaged, and its operation is described. Reliable emergency operation of the system with uniquely designed devices is shown. Preliminary test results for different gas flows and pressures are given. Measurements showed that the working gas flow in the tubes could be varied and the emergency tube shutoff threshold could be set within a wide range by changing the parameters of the above devices, first of all the weight of the balls and the size of the grooves in the seat.

It is worth mentioning that the device can be used in other systems with gas flows.

1) Asorskiy N. et al., NIMA, 824, 2016, 569.
2) The NA62 Collaboration, Journal of Instrumentation, May 31, 2017.
3) H. Nishiguchi et al., NIMA, 845, 2017, 269–272.
4) Myeong Jae Lee, Nucl. Part. Phys. Proc. 2016, 273–275
5) SHiP Collaboration, CERN SPSC-2015-016, SPSC-350, 8.04.2015.