SibTest 2015 IOP Publishing
Journal of Physics: Conference Series **671** (2016) 012023 doi:10.1088/1742-6596/671/1/012023

# Special Aspects in Designing High – Frequency Betatron

**A A Filimonov[1], S V Kasyanov[2], V A Kasyanov[3]**

[1]Senior research worker, lab 41, INDT, Tomsk Polytechnic University, Russia, Tomsk
[2]Senior research worker, lab 41, INDT, Tomsk Polytechnic University, Russia, Tomsk
[3]Head of laboratory 41, INDT, Tomsk Polytechnic University, Russia, Tomsk
E-mail: kassianov2011@yandex.ru

**Abstract.** The article is devoted to designing the high – frequency betatron. In high – frequency betatron most important problem is overheating of the elements of the body radiator unit. In an article some directions of solving this problem are shown.

## 1. Introduction

Last years, it can be seen the increasing market requests on betarons, specialized for custom inspection systems[1,2]. Betatron's advantages are:

- relatively low cost,
- low maintenance costs,
- low requirements for servicing personnel,
- ability to work in dual – energy mode.
- low power consumption good for mobile inspection systems.

Most serious betatron's disadvantages are low output dose rate in comparison with linac and lager dimensions of an accelerator, that causes increasing the weight of radiation protection shielding.

One of the most effective method of increasing the dose rate of a betatron is increasing the pulse repetition rate. This method will not cause increasing the weight and dimensions of the betatron radiator.

In institute of introscopy we gathered some experience on designing betatrons with high repetition pulse rate (Table 1). One of the most successful models is betatron for inspection system with energy 3 Mev and pulse repetition rate 400 Hz. Also there were designed betatrons on energies 5, 6.5, 7.5 MeV with pulse repetition rate 300 Hz, and 9 Mev with pulse repetition rate 400 Hz. Most exotic variant – betatron on energy 5 Mev with pulse repetition rate 900 Hz was designed for one American customer, it was experimental model. This model served as a basement to check some technical decisions and didn't go in commercial series

**Table 1.** Betatrons with high pulse repetition rate, *E* – experimental models, *C* – commercial models.

| E/freq | 3 | 5 | 6.5 | 7.5 | 9 |
|---|---|---|---|---|---|
| 300 | | | C | C | |
| 400 | C | E | | | C |
| 900 | | E | | | |

At a first sight, we can think that the question of designing the betatrons for custom inspection systems with pulse repetition rate 400 Hz was successfully solved, however it's worth to say that present models of high frequency betatrons have some unsolved problems, which reduces the areas of

Journal of Physics: Conference Series **671** (2016) 012023 doi:10.1088/1742-6596/671/1/012023

using them.

One of the most important problems is keeping normal temperature conditions.

As a rule, while designing betatrons for customs inspection systems it needs to minimize dimensions of the radiator, to reduce weight of a shielding and the weight of all system. According this direction, all electronic circuits are removed from the radiator to separate block. Removing electronic circuits from radiator also helps to decrease radiation loads on electronics components. Finally, radiator of the betatron for custom inspection system consists of magnetic guide, poles, central inserts block, magnetizing winding, and HV transformer with acceleration tube, situated between poles of a magnet.

According to our experience, normal work of a tube with HV injection unit, that connected through thyristors keys and uses double stage pulse forming circuit can be obtained for frequencies up to 400 - 500 Hz. Some tubes can work on frequency 600 Hz [3]. Higher frequency will cause the overheat of anode of the injector and output of the betatron will reduce to zero. The betatron on frequency 900 Hz that i mentioned before, could work on 900 Hz repetition rate not more than 10 seconds.

To go further in increasing the frequency of pulses we can apply the reduction of injection current using special forming circuits or using fully controlled injector [4]. The same time, reducing the injection current causes reduction of electron capture time and increasing the current of an injection. These questions for detailed experimental research.

Let's see the thermal picture of working betatron (figure 1).

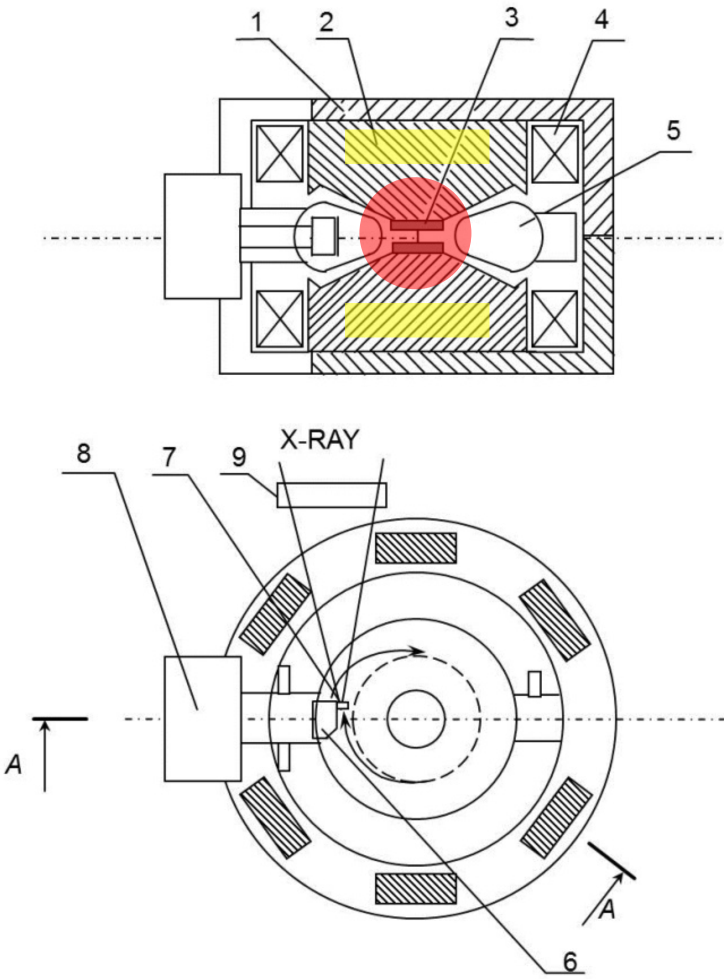
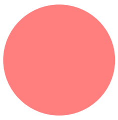



**Figure 1.** Construction of a betatron: 1 – magnetic guide; 2 – pole; 3 – central inserts block; 4 – magnetizing winding; 5 – tube; 6 – injector; 7 – target; 8 – HV transformer; 9 – dose rate monitor,


90 – 95 C in 20 minutes 400 Hz,


60– 65 C.

Most heat dissipation goes in electromagnet of betatron - in magnetizing winding and in the magnetic guide. The value of these energy losses gives more than half of all losses in units of betatron. That is why we should seriously think about choosing materials for electromagnet to improve temperature mode of a betatron. At first, improving the temperature mode of a betatron is reaching with using special transformer steel with lowest specific losses.

Usually, in inspection system the betatron radiator is housed in a massive shielding container. Most appropriate variant of cooling in a mobile inspection system is a axial or loop expulsion with air.

As usual, there is no problem with temperature mode of a magnetizing winding - you just need to choose right high frequency litzendrat wires and right fan for cooling it.

More problems we have in cooling magnetic guide, exceptionally central inserts block. Central inserts block consist of separate disks of magnetic guide material. These disks are separated with non - magnetic fiberglass material, which have high radiation resistance, high heat conductivity and high working temperature.

As it can be seen on figure 1, central inserts block can't be cooled by air flow, produced by cooling fan. In fact, cooling the central block goes through heat conduction from central inserts block to poles of the electromagnet. Cooling the poles goes through their side, and also through heat conduction from ends of a poles to the reverse magnetic guide. In betatrons with relatively low energy of accelerated electrons the gradient of temperature between reverse magnetic guide and the pole is not high and has a value about several degrees. While designing high frequency betatrons on energies 7 Mev and higher it's necessary to take additional actions to cool down the poles.

Good positive improvement is using additional heatsinks on a top and on a bottom of a radiator. Experiments with temperature mode of 9 MeV betatron shows, that using additional heatshinks allows to decrease the average temperature of a poles on 20 – 25 %. Also it gives effect for central insert block, however, its value is not so high, the temperature comes lower on 4–5 degrees.

Central inserts block is the most heat loaded element in betatron, and it's extremely undesirable to increase its temperature more than 100 C, higher values of temperature will cause the damage of it. In standard conditions with cooling fan the temperature of a central inserts block will reach 90 - 95 C after 20 minutes for betatron on 9 MeV with 400 Hz pulse repetition rate. And the poles will be heated to 60 - 65.

It's impossible to reduce temperature mode of central inserts block, using only air cooling, and we need more effective constructions for heat dissipation.

There was experiment on 9 MeV betatron to dissipate heat power from central inserts block with heatpipe.

Heatpipe is a vacuum closed device [5], that passing heat using locked evaporation condensate cycle with the contact with source of a heat from one side and heat receiver from other side (see figure 2). Heat energy is taken from source to the vapor area, and goes to boil the liquid, which comes to vapor. Heat comes in steam to other side of the tube, to the condenser area. Heat is taken by heat receiver (heatsink) and liquid condensates. The condensated liquid returns to vapor area through the capillary structure or just under the gravity force. So, instead of conduction heat transfer by electrons, that we have in solid metal caliduct, in a heatpipe the natural-convection heat transfer is used.

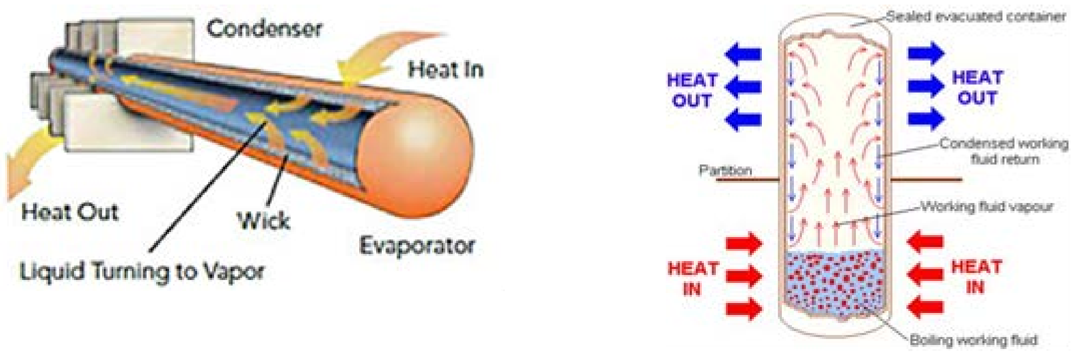



**Figure 2.** Construction and principles of work of a heatpipe.

Which advantages does the heatpipe give? At first, it's ability to move hundreds and thousands of watts of heat power. If we will evaporate several grams of liquid in second, it's possible to pass heat flow with value of several kilowatts.

Another interesting feature is ability to concentrate heat energy by using several heatpipes and configuring them for different. In a temperature range from 20 to 100°C wide range of heat transfer agents can be used - alcohol, halocarbon, ammonia, distillate water, ester.

In our case we used heatpipe from copper, 8 mm in diameter and 300 mm in length, filled with water for 8 – 10 percent of volume. There is a lowered pressure in pipe, allows to decrease temperature of boiling to 30–40°C. This heatpipe in using with heat source with temperature from 60 to 90°C can pass from 80 to 150 watts of heat.

The core of the central inserts block can be reached through the central bolt, which was made empty inside, and heatpipe was set inside it (figure 3).

There was a heatsink at the condenser area with additional fan. As a result, the temperature of the central inserts block reached 95 C after 60 minutes of work. After 15 minutes with radiation off it came to 60 C. In comparison, without using heatpipe temperature of the central inserts block reached 95 C after 20 minutes of work.

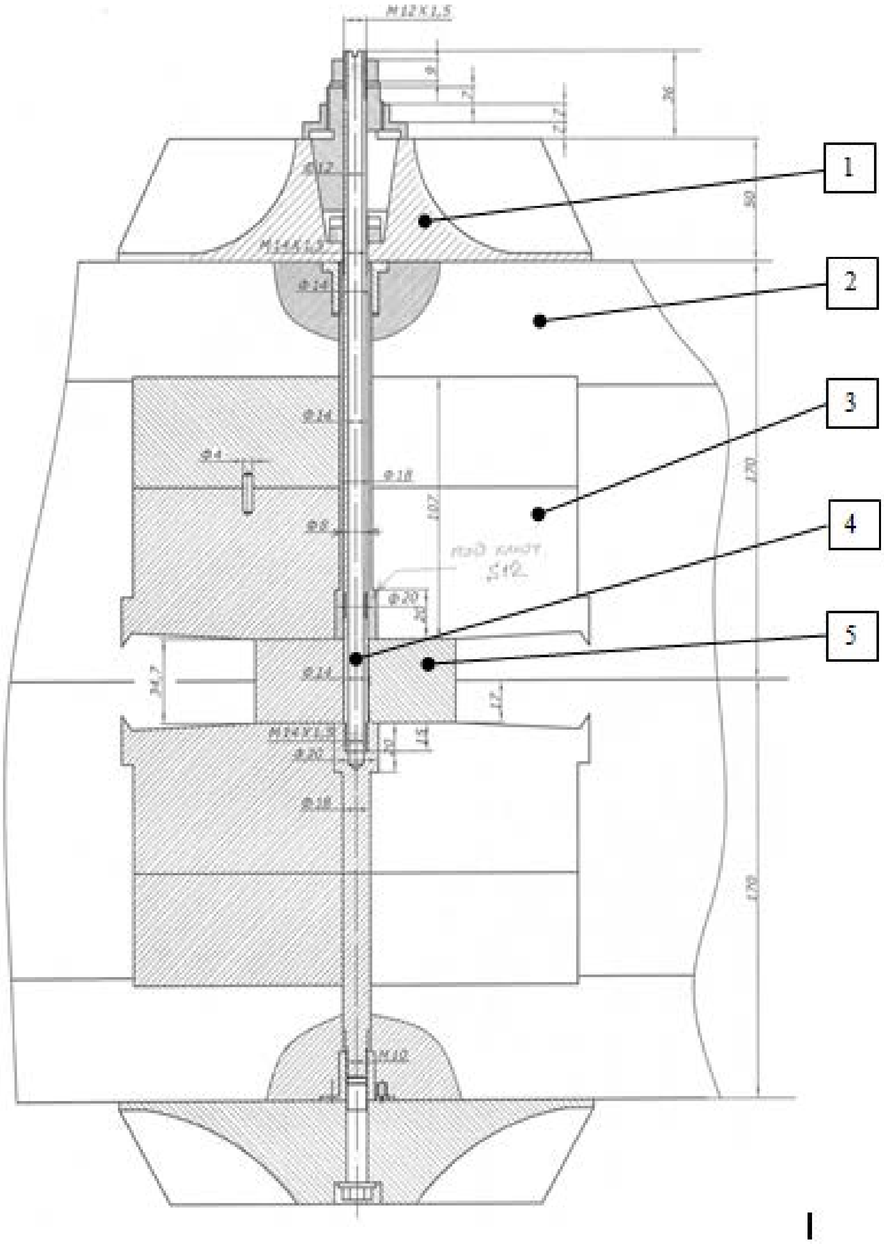



**Figure 3.** Heatpipe cooling system: 1 – heatsink, 2– reverse magnetic guide, 3 – pole, 4 – heatpipe, 5 – central inserts block.

Also there were experiments on cooling central inserts block with help of liquid cooling system. To take heat from the core of a central inserts block also central bolt was used. There is a special construction of a central bolt, where is the cooling liquid coming through it. Autonomic system of liquid cooling used pump, expansion tank, and a heatsink with fan.

For 9 Mev 400 Hz maximum temperature of the central block reaches 85 C in cycle 45 min on / 15 min off

The result is similar to using heatpipe. Heat pipe is more autonomic and reliable, but liquid cooling system is easier to repair and can be positioned in any angle, at the same time heatpipe should be positioned closer to vertical position, otherwise it will not work properly.

Journal of Physics: Conference Series **671** (2016) 012023 doi:10.1088/1742-6596/671/1/012023

Autonomic liquid cooling system is used in defectoscopy betatron on 9 MeV. It helped to decrease working temperature in the central inserts block from 110 C to 85 C.

These experimental results will determine the ability to design betatrons, that can have stable work on a frequencies up to 400 Hz.

## References

[1] http://portal.tpu.ru/departments/nii/nii_in/eng/Developments/SSB

[2] Stein M M, Kasyanov V A, Chakhlov V L, Macleod J, Marjoribanks P, Hubbard S (2004) Small-size betatrons for radiographic inspection *Palais des Congres. 16-th world conference on nondestructive testing* TS4.7.4

[3] Bel'tyaev Yu N, Pushin V S 1973 *Choice of the parameters of the injection system with a higher excitation frequency for a small betatron* (Proceedings of the scientific and research institute on nuclear physics, electronics and automatics of the Tomsk polytechnical institute, Atomizdat, Moscow) 15–17 [in Russian]

[4] Pushchin V S, Chakhlov V L (1975) Controllable injection for a high-frequency betatron *Ministerstvo Vysshego i Srednego Spetsial'nogo Obrazovaniya SSSR* 58–59

[5] http://www.thermacore.com/thermal-basics/heat-pipe-technology.aspx