DEVELOPMENT AND INVESTIGATION OF THE 2π BEAM LOSS MONITORS FOR SUPER-HIGH ENERGY ACCELERATORS. part 1. QUAD – BLM for 'warm' machines.

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Abstract

Described are the results on examination in the 70 GeV proton circulating beam of beam loss monitor (BLM) called QUAD, having been developed for the the UNK-I. The specific feature of QUAD is its special design: quasi-2π geometry of sensitive volume and installation directly on the accelerator beam pipe for increasing its sensitivity to the beam loss and reproducibility. The significant advantages of QUAD (air-filled, diaphragm-type, four-module ion chamber) against the traditionally remoted from the accelerator beam pipe BLM's have been proved. Experimental results are presented together with the computer simulation ones for investigated and for the TeV beam energies.

I. INTRODUCTION

In [1] the package of BLM's, developed for the UNK project on the basis of common approach to their design, was described. The advantages of these BLM's, having quasi-2π geometry of sensitive volumes and placed directly on the accelerator beam pipe, against the traditional ones were put forward on the basis of computer simulation results and the experience of beam loss monitoring in a high-intensity 70 GeV extracted proton beam. Nevertheless, some questions on this approach efficiency on circulating beam remained to be answered. The first industrial batch of QUAD's has been manufactured. The devices were tested, and the results are presented in this article.

II. QUADs TESTING IN THE U-70 CIRCULATING BEAM.

First of all, the effectiveness of the proposed concept on BLM's design in the 70 GeV circulating proton beam was examined with QUAD's in comparison with the traditional BLM's: Ar-filled Ion Chamber (ArIC) and Scintillating BLM (Sc). The performance of 'local' BLM's — QUAD's, installed directly on the accelerator beam pipe, and the 'remote' ones — ArIC and Sc., removed from the beam at a distance of about 1 m, has been investigated for the cases of local and remote sources of beam loss. Within the 'remote' class of BLM's, different types of them were compared: with- and without the inner amplification of signal. Analysing the data, we compared our results with

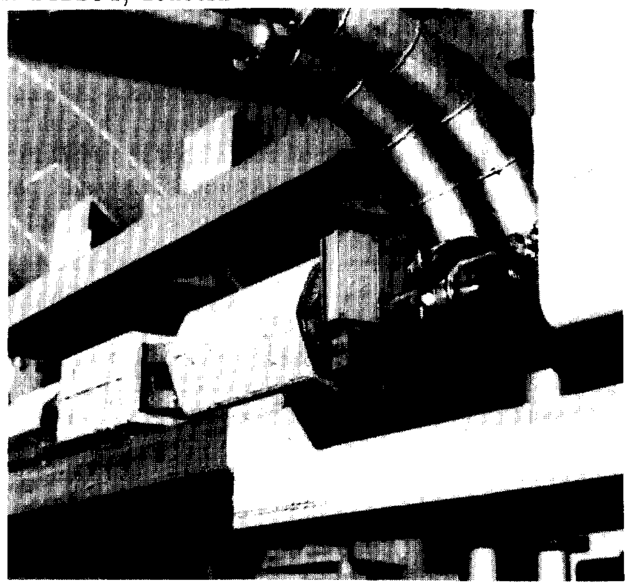

Figure 1: Common view of QUAD, installed on its duty position at the UNK-I ring.

[2], where the performance of 'remote' BLM's in a high energy proton beam was studied in detail. The obtained results completely agreed with conclusions of [2] for this class of BLM's. Briefly about the objects of the study:

- QUAD is a diaphragm-type, four-module, air-filled parallel-plate ion chamber with working gap 4mm and total active volume 0.9 litre, which correspondes to sensitivity 0.35 μA/rad$\cdot$s^{-1}. It is very handy in use device, self-tuning and -fixing directly on the accelerator beam pipe with any size and shape in the aperture ranging from 30 to 215mm. It needs only 60 mm of free space along the beam pipe to be installed and may be used in single, two- or four-channel operational mode. Other details are given in [1]. Fig. 1 presents the common view of the device, installed on its duty position in UNK-I ring.
- ArIC is an Ar-filled, 1.5 litre volume, parallel plate IC with 6 mm working gaps.
- Sc. — includes 10 cm^3 plastic scintillator, connected by means of a 1.2 m polished tube with a photomultiplier (PM), and placed in the median plane of the accelerator inside. Fig. 2 presents the scheme of BLM's study in the circulating beam. QUAD1 was installed upstream the septum magnet and QUAD2, ArIC and Sc. — downstream. Q1 and Q2 were installed on the 220 mm beam pipe at 3.5 m distance from one another.

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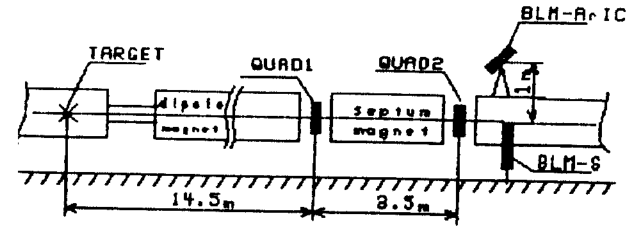

Figure 2: Scheme of BLM's study on U-70 circulating beam.

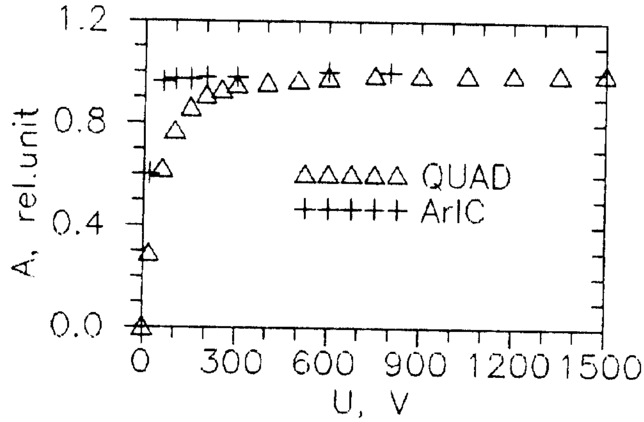

Figure 3: Bias curves of ArIC and QUAD in the radiation fields of about 1.0 and 60.0 krad$\cdot$s^{-1} respectively.

ArIC was placed on the top of magnet block 1 m vertically, and Sc. — in the median plane 0.75 m inside the accelerator. The partition of Septum magnet was considered as a local beam loss source and thick Internal Target 18 m ahead — as a remote one. The first question, we had to answer, was the correctness of our choice of Air for filling the IC-type BLM. Fig. 3 demonstrates the excellent performance of air-filled QUAD in the 60 krad$\cdot$s^{-1} radiation field, the hardest one, expected at the future machines.

We also calibrated the QUAD2. In its real position the specific response of Q2 to the beam loss on Septum magnet was $0.52\cdot10^{-3}$ pA/prot.$\cdot$s^{-1}, which agreed within 30% with the computer simulation results for real conditions and approximately agreed with the results of computer simulation in the TeV-energy region for the case of linear extrapolation in energy scale, corroborated for BLM's in [2]. The results on relative study of sensitivity, reproducibility and correlations of different BLM's are summarized in table 1. First of all, one can see the significant superiority in sensitivity of Q2 against the ArIC. It should be noticed, that in order to express the Q2 and ArIC relative sensitivity in correct terms, factor 20 from the table for local loss should be additionally multiplied by 3 (one should take into account the difference in their volumes and sensitive media). As a result, the total gain in sensitivity due to the geometric factor only, is about 60 for 70 GeV lost protons. Under real conditions of future machines the additional strong attenuation factor of shielding matter will take place. Summarizing all, we can conclude, that 'local' IC in the simple charge collection mode of operation provides the same sensitivity to the local beam loss as the 'remote' BLM with inner amplification of signal.

Conclusion 1: to be sensitive, BLM should be 'local'.

Table 1: BLM's relative sensitivities, reproducibilities and correlations

Specification of used Marks						
I-Beam Int.	1–Q1		11–.25Q1		2–Q2	
Local source of beam loss – Septum Magnet.						
Statistical parameter	Pair of objects for stat. processing					
	1-21	11-2	11-3	11-4	2-3	21-3
mean ratio	0.47	0.04	0.71	—	20.1	9.1
$\sigma_r(\%)$	1.6	6.0	3.7	6.3	0.6	1.1
correl.	0.63	0.76	0.88	0.70	1.00	0.96
Remote source of beam loss – Internal Target.						
Statistical parameter	Pair of objects for stat. processing					
	1-21	11-2	11-3	11-4	2-3	—
mean ratio	2.0	0.5	7.2	—	14.0	—
$\sigma_r(\%)$	0.5	1.0	11.6	11.6	7.3	—
correl.	1.00	1.00	0.52	0.53	0.46	—

Specification of used Marks						
I-Beam Int.	21–.75Q2		3–ArIC		4–Sc.	
Local source of beam loss – Septum Magnet.						
Statistical parameter	Pair of objects for stat. processing					
	2-4	21-4	3-4	1-I	21-I	4-I
mean ratio	—	—	—	—	—	—
$\sigma_r(\%)$	5.2	4.2	5.3	14.7	44.7	39
correl.	0.62	0.80	0.61	0.12	0.42	0.48
Remote source of beam loss – Internal Target.						
Statistical parameter	Pair of objects for stat. processing					
	2-4	—	3-4	1-I	21-I	—
mean ratio	—	—	—	—	—	—
$\sigma_r(\%)$	7.4	—	0.7	0.7	0.9	—
correl.	0.45	—	0.98	1.00	1.00	—

The accuracy (reproducibility) of Q2 and ArIC were in the case of local beam loss the same, to an accuracy of 0.5%, which also agree with [2], and their correlation coefficient was 0.999! On the contrary the accuracy and correlations have been dramatically lost, if we use Sc. monitor with inner amplification of signal.

Conclusion 2: inner amplification of signal is a great disadvantage of any BLM.

Mark '21' in the table is used for Q2 with a weakly violated geometry: one of four modules, namely – inner in the median plane, was switched off. Result: sensitivity decreased twice and accuracy deteriorated twice as well.

Conclusion 3: in the case of local loss the 'local' BLM should have 2π geometry of sensitive volume. With energy growth this demand becomes rigider. Some other conclusions can be extracted from this table, for example: beam halo weakly correlates with beam intensity.

Now let consider the case of remote source of beam loss. The situation changes. The 2π geometry of 'local' BLM isn't necessary now to provide the desired 0.5 – 1.0% reproducibility. Mark '11' in the table is used for Q1 with a strongly violated geometry: only one of four modules, namely – inner in the median plane, was switched on. But one can see no loss in accuracy, the sensitivity decreased only, proportionally to the active volume decreasing. One can see also the excellent correlations between Q1, Q2 and Intensity on the target on one hand and on the other hand — nice correlation between 'remote' BLM's and bad between them and QUAD's.
Conclusion next: in the case of remote beam loss, 'local' and 'remote' BLM's indicates different sources. Q1,2 indicates Intensity of remote loss, but ArIC and Sc. – ? May be the equilibrium background in the accelerator tunnel, because of their excellent correlation and relative reproducibility. In any case they are useless to signal the dangerous situation for strong remote beam loss.

Finally we can conclude that air-filled QUAD is very sensitive, precise, handy and flexible in use BLM, absolutely adequate for different applications in high-energy "warm" machines in addition to its primary function. While it is very sensitive and reproducible, it can be used in the multichannel operational mode for alignment of some accelerator equipment, scrapers for example, for beam halo study, ⋯ The only advantage of Sc. BLM against the IC ones is its very fast response to the instantaneous loss – in the ns range. But it is hard to imagine, where this advantage possibility may be taken in the beam loss monitoring.

One can see, that some results in table 1 are contradictory and the table needs to be completed with some data. So, we are planning to complete the set of 'remote' BLM's with an extended IC, similar to the one, used in [2]: fabricated from spirally insulated, air dielectric coaxial cable. The reason is,that the extended 'remote' BLM (but in proportional operation mode, which is worse, see concl. 2 and in addition a rather complex intercalibration problem needs to be solved in this case), has been now announced as the main competitor to our proposals both for 'warm' and SC machines, see part 2 of this work. [3]. We are also going to provide these measurements with more accurate loss and beam intensity monitoring. The 'Sc.' BLM also should be modified to be compatible with the electronics we used for IC monitors: a current to frequency converters [4]. We will try also to complete our experimental setup with a shielding matter between Septum magnet and 'remote' BLM's in order to simulate correctly their real environment in the future high-energy 'warm' machines.

III. CONCLUSIONS

The main conclusion: the right way on the designing of BLM's with 2π-geometry of their sensitive volumes for the beam loss monitoring on super-high energy machines is proved in all principal points by means of experimental study on circulating and extracted 70 GeV proton beams. The proposed IC-types BLM's combine a capability for high dose rates with a sensitivity and precision, which allow the interpretation of minute perturbations that may signal the onset of a failure. They will provide very sensitive, reproducible, reliable and handle beam loss monitoring to be used in addition to their main specification as a diagnostic tool for beam halo study at extremely low levels, starting from 10^4–10^5 protons in sub-TeV region of energy, and in some other applications. This paper is the first half of a common work and is devoted to the beam loss monitoring in the 'warm' machines. The second one, to be presented at this Conference also, is devoted to the case of beam loss monitoring in the SC accelerators.

Although the main address of our activity are the SC accelerators-colliders, the high-energy, high-intensity "warm" machines also need an effective tool for beam loss monitoring, and, on the other hand, they may be considered as the excellent test-site to accumulate experience in BLMS use in different applications. Unfortunately this work cann't be carried out completely in our existing 70 GeV machine, where we found only several places for QUAD installation, although it needs only 60 mm of free space along the beam pipe to be installed. So, we are waiting for the commissioning of UNK-I, 400 GeV proton ring, to test the declared new possibilities of BLMS, based on the QUAD's. [5].

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