

# A New Concept of a Higher-Order-Mode Damper for the KAON Booster Cavity

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## Abstract

A new type of higher-order-mode damper for the ferrite tuned rf cavity for the proposed TRIUMF KAON Factory Booster synchrotron is presented. This HOM damper is in the form of a 5-element coaxial high-pass filter and is appended at the gap of the rf cavity. The design concept and prototype realization of such a filter in coaxial form are outlined. Measurements show that higher-order modes up to 700 MHz are damped significantly, with very little power being absorbed at the fundamental frequency of the ferrite tuned cavity that varies from 46 MHz to 61 MHz.

## 1. INTRODUCTION

A large number of modes can be excited in the ferrite tuned booster cavity by a bunched beam. The voltage induced in the cavity due to these higher order mode frequencies can lead to transverse and longitudinal beam instabilities. Since the induced voltage is proportional to the shunt impedance of the higher order modes, this impedance must be lowered significantly. The coaxial high-pass 5-element filter as a HOM damper presented in this paper damps the longitudinal HOM's without excessive damping of the principal accelerating mode. As the frequency of the ferrite tuned cavity swings from 46 to 61 MHz [1], the higher order modes are dispersed over a broad range. This filter is a broad band device since it damps such a wide range of higher order modes. To achieve broad bandwidth, it is advantageous to incorporate the damper inside the accelerating cavity [2,3,4].

## 2. DESIGN CONCEPT

The design aim is to find a damper which will provide low shunt impedance below 1 k $\Omega$  for all the higher order modes, has high shunt impedance for the principal accelerating mode and demonstrates above performance as the frequency of the accelerating mode swings from 46 to 61 MHz. The damper should also be designed to withstand accelerating gap voltage of 60 kV. The proposed coaxial high-pass filter is designed to meet the above requirements.

The corner frequency of the high-pass filter is chosen so that the current due to the first higher order mode flows into the 50 ohm terminating loads with least attenuation, while the highest fundamental frequency, namely 61 MHz, has at least 40 dB attenuation. The basis of the design is determined by the above filter specification which dictates the number of filter elements and component values [5].

### 2.1 A 6 inch model of the coaxial filter

A 6 inch model of the 5-element high-pass filter was initially designed, fabricated and tested with a  $\lambda/4$  transmission line cavity to evaluate the performance of such a damper. The filter consists of three discs which form the capacitance's and four rods which constitute the two inductors. Four 50 ohm loads are connected to the third disc by short non-inductive straps [6]. A corner frequency of 150 MHz for the filter was chosen.

### 2.2 Coaxial filter with a horn

A filter structure as described in section 2.1 constitutes a three gap structure for the passing beam. Also, any resonance of the filter with high impedance will produce beam induced voltage similar to that produced by HOM's. By introducing a horn, which is equivalent to a series capacitance and a shunt inductance, between the cavity gap and the first filter disc, the coupling of beam current to the filter resonance's can be minimized. The horn does resume the single gap structure of the cavity and provides a higher attenuation for the principal mode since the addition of horn has modified the 5-element to 7-element filter.

### 2.3 Full scale HOM damper

The excellent performance of the 6 inch model led to the design of the full scale HOM damper for the ferrite tuned booster cavity. Figure 1. shows the coaxial filter and part of

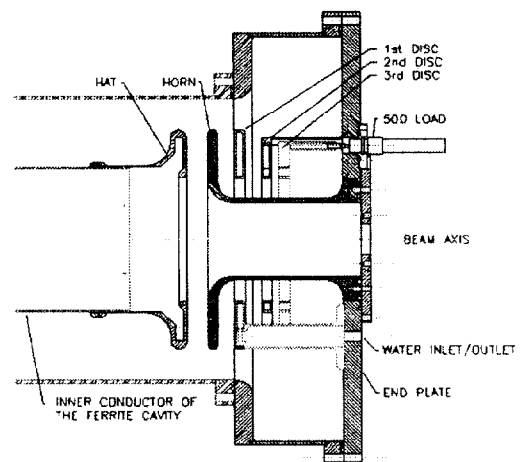


Figure 1. The high-pass coaxial filter and part of the cavity.

the ferrite cavity. The capacitances of the filter are formed out of hollow coaxial discs and the inductors are hollow rods connected between end plate and their respective capacitive discs. The filter components are self supporting. The inductive rods which support the capacitive discs are used for water inlet and outlet for cooling both the inductors and the capacitors. The last disc is supported by four rods which connect to the four water cooled 50 ohm terminating loads. The rods are welded to the end plate after the gaps between the discs and the lengths of the inductive rods are optimized for best filter performance.

A hat was added to the inner conductor of the ferrite cavity to obtain the required capacitance for the filter. A hollow tube concentric with the beam axis, and a disc of the same diameter as the hat is welded to this tube to form the horn. This addition made the structure a 7-clement high-pass filter.

### 3. SIGNAL LEVEL MEASUREMENT

Most of the signal level measurements are done with a HP network analyzer. The Q of the cavity is measured with two loosely coupled capacitive probes. The shunt impedances are measured with the bead pull method and other conventional techniques.

#### 3.1 Measurement of the 6 inch model

The performance of the filter with and without the horn is evaluated from Q and shunt impedance measurements. In both cases the pass-band is 1 GHz, the pass-band ripple is 3 dB and the corner frequency is 150 MHz. The filter with the horn shows an increase in attenuation >5 dB for frequencies below 50 MHz and its frequency response is shown in fig. 2.

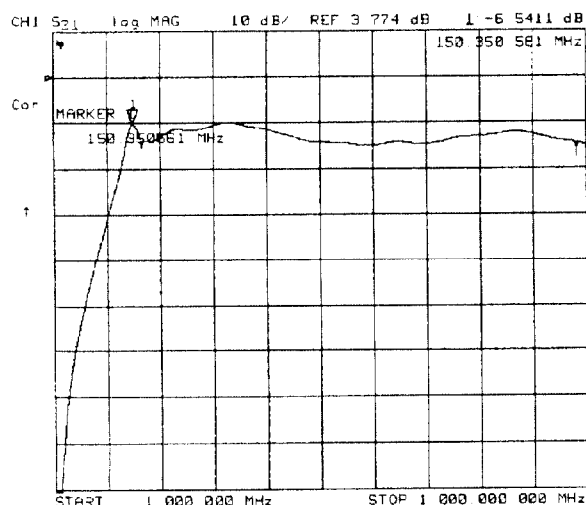


Figure 2. Frequency response of the 6 inch filter with horn.

The filter as a damper is tested with a  $\lambda/4$  test cavity whose resonant frequency is 65.87 MHz. Q and shunt impedances of

the test cavity for the frequency spectrum of 1 GHz are measured with the damper unloaded and loaded with 50 ohm terminating resistors. Table 1 lists the measurement data

Table 1  
Q and shunt impedance of 6 " cavity and filter without horn

F MHz	Unloaded		Loaded		Damping %
	Q	R shunt Ohms	Q	R shunt Ohms	
65.866	2041	96000	2036	94000	2
204.984	1760	32000	38	700	98
327.989	1182	7300	7	40	99
413.638	1150	1000	39	30	97
515.328	2210	2000	<2	<10	99
571.632	1400	6000	<2	<10	99
640.614	228	1000	<2	<10	99
653.965	867	500	39	10	96
713.943	619	2000	300	1000	50
797.239	559	500	36	30	94

with the exception of a TM 0,1 mode at 713.94 MHz, the filter provides excellent damping of 94% or greater for all the higher order modes up to 1 GHz and damps only 2% for the principal mode.

#### 3.2 Measurement of the full scale model

The filter response of the full scale damper was measured in the same way as section 3.1. However the pass band is limited to 700 MHz instead of 1 GHz and the pass band ripple is 10 dB. The filter shows a strong circumferential mode at 460 MHz which is related to the diameter of the discs of the filter. Table 2 shows quality factor Q and shunt impedance of the full scale coaxial filter with horn attached.

Table 2  
Resonances of full scale HOM damper with horn

Mode	F MHz	Unloaded		Loaded		Damping %
		Q	R <sub>shunt</sub> Ohms	Q	R <sub>shunt</sub> Ohms	
Fundamental	205	2000	23900	10	100	99.5
	440	1000	1300	240	300	76
TM 0,1	460	1100	5200	940	4400	14.5
	503	1750	300	75	100	95.7
3rd Harm.	601	1900	300	<5	<10	>99
	738	1500	1400	300	300	80

It can be seen from the table that as soon as the filter is terminated with 50 ohm loads, all the high shunt impedances and Q's are damped except for one TM 0,1 mode at 460 MHz. With the damper installed on the booster cavity, unloaded and loaded Q of the cavity for frequencies up to 1 GHz were measured. Figure 3 shows that the higher order modes are damped significantly up to 690 MHz where only 4% loss of Q is encountered at the fundamental frequency of 48.5 MHz.

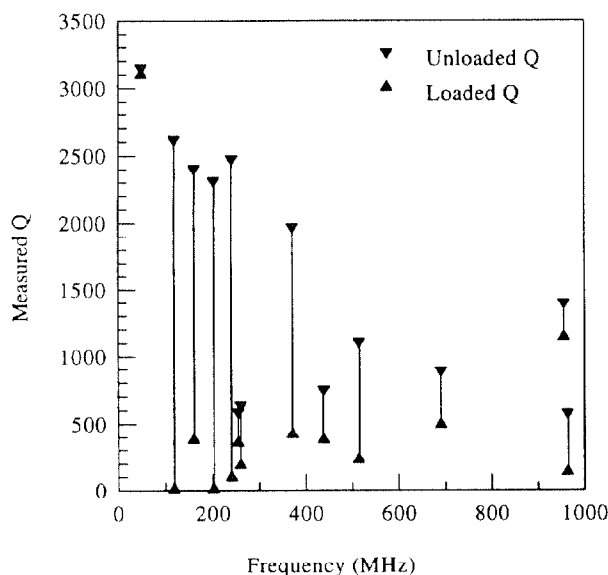


Figure 3. Q measurement of the ferrite tuned cavity with the HOM damper installed.

The shunt impedances could not be measured accurately since the stability of the dc bias power supply for the ferrites was not adequate.

#### 4. HIGH POWER TEST

The full scale HOM damper was installed on the ferrite tuned booster cavity for high power test. A hat was added to the inner conductor of the ferrite cavity at the gap end to form the first capacitance of 10 pF of the filter. The cavity damper system was rf conditioned under a vacuum of  $1.2 \times 10^{-6}$  torr. With a dc bias current of 1320 amps on the ferrites, the cavity frequency was 47.80 MHz. 60 kV cw at the accelerating gap of 20 mm could be maintained without any difficulty. The gap voltage was calibrated using x-ray measurement. Under low duty cycle pulse condition, a voltage of 80 kV at the gap could be achieved without any breakdown. The power absorbed at one of the four 50 ohm terminating loads with a gap voltage of 63 kV was measured to be only 11 watts and was found to agree with the predicted value of 5 watts from signal level measurement.

Similar measurements at the fundamental frequency of the cavity were carried out with the horn installed in the damper. The gap between the horn and the inner conductor of the ferrite cavity was also kept at 20 mm. The damper with the horn couples 2 dB less power than without the horn. The gap voltage was kept at 60 kV under low duty cycle pulse instead of cw due to time constraint.

#### 5. CONCLUSIONS

The signal level and high power tests definitely show that this new type of coaxial filter performs well as a higher order

mode damper. The horn version is more attractive since the corner frequency can be designed very close to the first higher order mode without coupling appreciable fundamental power. In fact the measured voltage attenuation of 56 dB at 48.3 MHz with a corner frequency of 126 MHz is more than satisfactory. This type of damper does not suffer from excessive coupling of power at the fundamental frequency. The loss of Q at 48.3 MHz was measured to be only 4 %. The filter resonances and circumferential modes of the filter structure should be suppressed or eliminated since they tend to limit the pass band of the filter. Circumferential modes can be eliminated by cutting radial slots on the discs or cutting the discs into half (this makes water cooling a difficult design). The rods which constitute the inductors are shorted at the end plate and are loaded by capacitive discs to form a  $\lambda/4$  stub. For the above damper this resonance is close to 700 MHz. The rods that connect the last disc to the 50 ohm terminating loads should be non inductive. Minimizing the lengths of these connecting rods is of utmost importance. There is a scope of optimization of the filter components with regards to higher bandwidth of the filter. Numerical modelling using MAFIA could be used for further studies of the damper [7]. A five element filter with a horn may be adequate for most of the applications.

#### 6. ACKNOWLEDGMENTS

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