WAVEGUIDE TRUNK WITH EXTRA LOW LOSSES FOR MICROWAVE DIAGNOSTICS OF OBJECTS AT FAR DISTANCES

Gaynulina E.Yu.[1], Mineev K.V.[1], Orekhov Yu.I[1]., Sedov A.A.[2], Shalygin A.A. [2], Mitin E.S [2]

[1]FRPC NIIIS n. a. Yu.Ye. Sedakov, Nizhny Novgorod, Russia
[2]RFNC-VNIIEF, Sarov, Russia

Microwave radiointerferometers (RI) are widely applied for fast gas-dynamic processes diagnostics [1].

Gas-dynamic processes specificity requires placing RI receiver-transmitter at a safe distance from the object and, at the same time, to placing antenna (radiator) close to the object studied for its probing and reflected signal receiving. Dielectric waveguides (DW) are widely use in microwave diagnostics due to their flexibility and low cost, which is important for single-time usage in explosive experiments [2]. However, DW losses (2.5-3) dB/m are limiting waveguide trunk length (10 m) for the RI used. Therefore, waveguides losses reduction is extremely important for the expansion of RI usage opportunities and fundamental for sensitivity increasing of the radiometric RI mode during fast processes thermal characteristics measuring [3].

Indeed, the accuracy of measurement of object`s movement parameters, such as its displacement, increases with the power of useful signal to noise power ratio at the output of the measuring system [1]. The noise level is mainly determined by the instrument and therefore does not change, while the level of the useful signal depends on the power losses in the antenna system. In particular, the measurement error increases with increasing of the transmission lines length.

Thus, to reduce measurement error it is necessary to reduce losses in the transmission lines by an order compared to the DW linear losses. This problem has a particularly actuality for remote temperature measurements using radiometers of microwave range, and when used for sensing objects in radiointerferometry of submillimeter wavelength range.

Well-known and widely used oversize metal waveguides (OMW) with rectangular and circular cross-sections, that provides linear losses by an order smaller than waveguides with standard cross sections, when the size of the waveguide`s cross section D to the wavelength λ ratio equal to D/λ=5...20 [4]. So, rectangular OMW with H_{10} wave and section 22,8×10,2 mm^2 provides the losses of 0.23 dB/m at λ=2 mm, 20 times smaller than the MW with standard section. Circular cross-section MW with the H_{11} wave and diameter of 24 mm provides linear losses of 0.1 dB/m at λ=3 mm [4].

When designing a transmission line (TP) on OMW a potential multimode regime of wave propagation needs to be considered. The number of possible wave types is proportional to the ratio S/λ^2, where S is the cross-sectional area of the waveguide.

For this reason, sharp irregularities are unacceptable for TP on oversize waveguide, and the optimal excitation of these TL, in accordance with the quasioptic principles, provided by Gauss-Hermite wave beam with the beam`s width w (0.5) to the waveguide`s diameter D ratio equal to w/D=0,5...0,6 [5].

The report illustrates the TP on round OMW with the H_{11} wave. Unlike rectangular OMW, waveguide irregularities, in addition to higher wave types excitation, lead to the polarization waves instability. For this reason, it is advisable to execute on round OMW only straight-line sections of TL, and to provide TP flexibility on the end sections by flexible DW.

As the basis of the TL was selected a copper pipe ДКРНМ 28×2 М1 ГОСТ 617-2006, widely used in the industry.

As horn exciters of TP conical horn with apex angle 12^0 and the horn length L to λ ratio equal to 40 was designed. It provides the phase distribution of the field in the horn aperture, close to in-phase.

In addition,a two-mode horn was designed, which has both the main H_{11} and E_{11} wave excited. When the ratio of their amplitudes is 1:0.6 and phases at the exit of the horn are equal, the field distribution close to Gaussian is realized.

Numerical modeling and development of TL was performed on circular waveguide, made on the above mentioned size copper pipes with the ratio D/λ=8.

Using the developed horn exciters calculated frequency dependence of the transmission coefficient have an oscillating character and changes within 0.05...0.5 dB/m in the frequency band width of 5 GHz (if λ=3 mm). Moreover, it is possible to ensure the losses not worse than 0.2 dB/m in the frequency band of 2 GHz or not worse than 0.3 dB/m in the band of 3 GHz by changing the length of the TL section within ±λ limits.

The oscillating nature of the frequency dependence of losses in the oversize waveguide is explained by imperfect excitation of TL by developed horns and lack of self-filtering of the excited higher waves types properties, responsible for the oscillations of the transmission coefficient. The experimental results are close to the calculated ones. So, on the length of TL equal to 2.5 m, linear losses of 0,5...0,65 dB/m was obtained in required radio interferometers bandwidth.

A further reduction of losses, as shown by the simulation results, can be achieved by using of the considered circular cross-section OMW with dielectric film with thickness 0.2 mm on the inner surface of the pipe. The film may be made of materials with parameters ε=2,1...2,5, tg $\delta=10^{-4}$.

Such metallo-dielectric waveguide (MDW) belongs to the "hollow dielectric channel" class [5]. The partial plane wave of excited wave beam in waveguide (Brillouin waves) falling on the inner dielectric boundary under small angles and are reflected from it effectively (unlike the higher types of waves), so creating a HE_{11} wave. Due to this, ohmic losses in the MDW is significantly lower than in the same waveguide without the film, and self-filtering of higher types of waves is ensured.

When such MDW excites by main order Gauss-Hermite wave beam the losses in MDW with diameter of 40 mm at λ=2 mm and the thickness of the dielectric film of 0.2 mm can reach 4 dB/km [5].

Modeling of TP based on the MDW that contains oversize metal tube with a dielectric film thickness of 0.2 mm on the inner surface, with use of the developed horn trancitions, showed significantly better frequency uniformity of the losses in the range of 0,1...0,2 dB/m.

Thus, the developed TL based on oversize metal waveguide provides a linear losses of about 0.5 dB/m. Using of this TP in typical radiointerferometric experiments with the length of TL equal to 10 m, provides a gain of 50 dB in the attenuation in the forward and backward passage compared to DW (3 dB/m), which significantly affects the accuracy of measurement of gas-dynamic process displacement.

Using of such TL in the radiometric circuit for measurement of the brightness temperature with TP 2 meter length, provides increasing of measurement accuracy up to 50 K instead of 250 K- 280 K when using DW.

Development of technology of film coating on the inner surface of the TL will further reduce linear losses up to 0,1...0,2 dB/m, which in general will lead to a qualitatively new level of microwave diagnostics of dynamic processes.

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ПРОТОННАЯ РАДИОГРАФИЯ БЫСТРОПРОТЕКАЮЩИХ ПРОЦЕССОВ НА БАЗЕ УСКОРИТЕЛЯ У-70. НОВЫЕ ВОЗМОЖНОСТИ

Ю.А. Трутнев, А.Л. Михайлов, М.А. Сырунин, И.А. Ткаченко, В.А. Огородников,
А.П. Цой , А.И. Лебедев, К.Н. Панов, Б.И. Ткаченко , В.А. Аринин, О.В. Орешков,
М.В. Таценко, С.А. Картанов, И.В. Храмов, Ю.П. Куропаткин, К.Л. Михайлюков,
[1]А.В. Максимов, А.А. Матюшин, М.С. Михеев, Н.Е. Тюрин,
Ю.С. Федотов, Э.А. Людмирский, О.В. Зятьков

РФЯЦ – ВНИИЭФ, Саров, Россия
[1]ФГБУ ГНЦ ИФВЭ, Протвино, Московская обл., Россия

Протонная радиография на базе высокоэнергичных протонов, обладающая целым рядом преимуществ по сравнению с импульсной рентгеновской радиографией, раскрывает широкие возможности для невозмущающей диагностики быстропротекающих процессов. Ранее в работах [1], [2] сообщалось о радиографическом комплексе на базе протонного ускорителя У-70 для исследования как статических объектов, так и быстропротекающих процессов [3-8].

Основные преимущества импульсной протонной радиографии быстропротекающих процессов, реализованной на ускорителе У-70, перед широко распространенной импульсной рентгеновской радиографией:

- существенно большая многокадровость регистрации динамического процесса, сопровождающегося, как правило, уничтожением объекта регистрации;
- на порядки более широкий динамический диапазон регистрации распределения массовых толщин ($\rho \cdot l$) просвечиваемого объекта;
- в разы большие массовые толщины просвечиваемых объектов (до ~ 450 г/см^2), недостижимые на наиболее мощных современных рентгеновских радиографических комплексах, созданных на базе ускорителей электронов МэВ-ного диапазона энергий;
- лучшее в 2-3 раза пространственное и временное разрешение.

В настоящее время возможности протонного радиографического комплекса (ПРГК) на базе ускорителя У-70 существенно расширены:

- создана новая магнитооптическая система формирования изображения и управления пучком протонов, вследствие чего поле обзора (диаметр протонного пучка) увеличено в ~ 4 раза до ~ 200 мм, рисунки 1,2;
- реализовано управление диаметром зондирующего протонного пучка от ~60 мм до ~240 мм в зависимости от размеров исследуемого объекта и требуемой плотности потока протонов;
- созданы широкоапертурные многокадровые системы регистрации изображения объекта и мониторинга качества пучка в каждом протонном сгустке (“банче”) по ходу пучка, расположенные на трех позициях: одна позиция – до объекта (мониторинг пучка), две – после (регистрация изображений объекта), рисунок 3;
- в ~ 6 раз увеличено достижимое общее время регистрации динамического объекта за счет “порционного” быстрого резонансного вывода протонов с паузами между порциями банчей, кратными времени пробега банча протонов по орбите их ускорителя;
- разработаны взрыволокализующие системы для размещения диагностируемого динамического объекта в пучке протонов с полной локализацией продуктов его взрыва при