## Session 3. Klystrons

April 29 (Monday) / 10:20 ~ 12:20 / Room 3

Session Co-Chairs: Ming-Chieh Lin (Hanyang University, Korea)
Young-Soon Bae (National Fusion Research Institute, Korea)

10:20 ~ 10:40
**3.1 / [Keynote] Simulation of High-Efficiency Klystrons with the COM and CSM bunching**

Andrei Baikov (Moscow University, Russia), Olga Baikova (National Research Nuclear University, Russia)

The two types of high effective bunching in powerful klystrons are discussed. The first bunching type, named COM, is intended for standard klystron structure with first harmonic cavities only. The second bunching type, named CSM, is realized in klystron structures which includes cavities of second and third harmonics. Both bunching types allow to reach the klystron efficiency up to 90%.

10:40 ~ 11:00
**3.2 / High Efficiency Klystrons for ESS**

Chiara Marrelli (European Spallation Source, Sweden)

A high efficiency klystron making use of second and third harmonic cavity bunching method (Core Stabilization Method) has been developed. This tube would be able to produce up to 1.5 MW of pulsed RF power at 704.42 MHz, and it is compatible with the requirements for the klystrons for the medium and high beta part of the linac of the European Spallation Source.

11:00 ~ 11:20
**3.3 / Design Study of High Efficiency CW Klystron for CEPC**

O. Z. Xiao (Chinese Academy of Sciences, China), Z. S. Zhou (Chinese Academy of Sciences, China), Zaid-un-Nisa (Chinese Academy of Sciences, China), S. C. Wang (Chinese Academy of Sciences, China), G. X. Pei (Chinese Academy of Sciences, China), D. Dong (Chinese Academy of Sciences, China), S. Fukuda (High Energy Accelerator Research Organization, Japan)

In order to reduce energy consumption and operating cost for CEPC, the 650MHz/800kW high efficiency klystron has been regarded as a priority key technology to be researched and developed. In this paper, the recent progress of high efficiency CW klystron for CEPC is reviewed briefly. Then the RF section design study of the second stage of high efficiency klystron for CEPC is presented. Several computer codes have been used for klystron simulation. The simulation results with different codes are presented, which are in good agreement. The whole klystron simulation using 3D PIC solver in CST indicated that the klystron efficiency was

achieved up to 78% with asymmetry coaxial coupler.

11:20 ~ 11:40

**3.4 / Klystron efficiency optimization based on a genetic algorithm**

HAMEL Pierrick (IRFU CEA, France), PLOUIN Juliette (IRFU CEA, France), MARCHAND Claude (IRFU CEA, France), PEAUGER Franck (BE-RF-SRF CERN, Switzerland)

This paper presents a method based on a genetic algorithm optimization to design a high efficient klystron, operating in the X band. First, the genetic algorithm is used to optimize the bunching circuit and then to optimize the geometry of the output cavity. Finally the output cavity is integrated to the bunching circuit and the achieved efficiency is about 70%.

11:40 ~ 12:00

**3.5 / Energy Efficient Klystron Operation at Saturation: Possibility due to Novel Modulator**

Rutambhara Yogi (European Spallation Source, Sweden), Carlos Martins (European Spallation Source, Sweden)

The European Spallation Source (ESS) will be the world's most powerful pulsed neutron source by the end of the decade. The beam of protons will be accelerated by 155 amplifiers, out of which 126 are klystron amplifiers. Following the present state of art, the Low Level RF (LLRF) system will generate an input signal for the amplifier that drives the cavity to the field with an amplitude and phase that are within 0,1% and 0,1 degrees of the set value. To achieve this, ESS needs the LLRF overhead of 25%. As the differential gain of klystron at the saturation is nearly zero, the LLRF system needs to operate the klystron back-off from the saturation in the linear region by about 15-25 %. This leads to the two disadvantages: need for infrastructure with higher power capability and operation of the klystron in energy inefficient zone.

The present paper discusses the novel concept of operation of klystron at saturation and modulating the cathode high voltage delivered by the modulator to achieve modulation of the klystron RF output power. This avoids klystron operation in the linear region and will reduce the requirement on the amplifier power by 25% and at the same time increases the efficiency at the operating point by 15-20%. In the context of ESS operation, it will lead to energy savings of 7.5GW-hr per year. The energy saving leads to an operational cost saving of about 10 MEUR for 25 years. It will also minimize the wasted energy conversion into heat, thus minimizing the cooling and the ventilations costs.

12:00 ~ 12:20

**3.6 / A miniaturized high-gain, high-efficiency metamaterial assited S-band extended interaction klystron**

Xin Wang (University of Electronic Science and Technology of China, China), Zhaoyun Duan (University of Electronic Science and Technology of China, China), Fei Wang (University of Electronic Science and Technology of China, China), Shifeng Li (University of Electronic Science

and Technology of China, China), Shengkun Jiang (University of Electronic Science and Technology of China, China), Yubin Gong (University of Electronic Science and Technology of China, China), Baidyanath Basu (Supreme Knowledge Foundation Group of Institutions, India)

We proposed a miniaturized S-band extended interaction klystron (EIK) assisted by metamaterial. The interaction structure of the EIK consists of a cylindrical resonant cavity filled with a metamaterial (complementary electric split-ring resonator) array. The study based on CST Eigenmode Solver predicted that the transverse cavity dimension of the proposed metamaterial assisted EIK is 1/3-1/2 times smaller than that of its conventional counterparts, while the device delivers typically 122 kW power, 53.5 dB gain and 43.5% electronic efficiency with an input drive of 0.27 W for typical beam and magnetic field parameters. The proposed metamaterial assisted EIK has potential applications in radar, industrial heating, accelerator, and satellite communications.