Dual Axis SRF Structures – 'The Best of Both' Linear and Circular Accelerators

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Introduction: The energy-frontier particle accelerators have recently lost their edge, because of conventional approaches to RF systems in both circular and linear accelerators. Machine designs based on single-axis RF structures (both normal- and super- conducting) come short to satisfy critical requirements of energy efficiency, operational cost and compactness. Introduction of new ideas is needed to revitalize the conventional accelerators to make them attractive. This is especially important as new ideas and technologies associated with the different flavours of Wakefield Acceleration are still at the preliminary stages and some of them may require 10 to 20 years before they maturate enough to spawn future high-energy and nuclear physics applications. Here we call attention to promising studies of dual-axis asymmetric SRF structures and their applications in high-energy machines. This new RF technology would allow one to combine benefits of linear and circular machines, as well as Energy Recovery Linacs (ERL) enabling efficient high current operation.

Motivation: We propose a novel cavity design that could solve challenges associated with the design of the state-of-the-art energy-frontier efficient accelerators for particle colliders, light sources and industrial applications. The outlined research program is aimed at development of the SRF technology to support a dual-axis asymmetric cavity [1-5]. Such structures look promising to enable ERL high-current operation [2-4] and usage of energy recovery technology less than ideal electron beams [5]. These capabilities can be beneficial for a broad range of applications including high-energy and nuclear physics, next generation Free Electron Lasers, finding its niche in the industry. Many applications including light sources and electron beam cooling require average currents to be as high as possible, which demands continuous wave (CW) operation, which is only achievable with superconducting RF structures. A large number of accelerator facilities make use of only a small fraction of the beam energy and energy recovery is needed to improve the efficiency, while the dual-axis cavity configuration 'unleashes' high current operation capabilities.

Dual-Axis RF Structures: Current state-of-the-art energy recovery in compact SRF LINACs can be facilitated as follows: **a)** with two independent sets of cavities, where recovered energy travels between cavities via RF waveguides and couplers; **b)** using the same cavity, where the returning beam is time-delayed and sent through the same cavity for deceleration. Recently proposed dual-axis asymmetric cavity allows one to localize High Order Modes (HOMs) thus increase the BBU threshold current [4], and support asymmetric operating eigenmode [5], enabling creation of the ultimate performance ERL system. In such system the energy recovery is achieved along the cavity second axis, which "pump up" the operating mode used to accelerate the electrons along the first axis. The amplitude and overall longitudinal structure of the operating mode on these axes can be different, allowing operation with spent and degraded beam. In the asymmetric dual-axis ERL the HOMs are not coupled between the axes allowing higher currents to be utilised without excitation of adverse beam instabilities. The research teams from Jefferson Lab (JLAB) constructed and tested the key component of such a structure [1,6,7]: dual-axis cell demonstrating technological capabilities of a prototype system.
Here, we propose to invigorate development of dual-axis SRF cavity by considering a "U- shape" system, which in general can be reduced to "H" or "h" systems. The concept (dual-axis asymmetric system) may also be extended to a broader range of the accelerating structures. We would like to initiate proof-of-principles studies which would ultimately lead to prototyping and testing of the dual-axis asymmetric structures in energy recovery mode.

Possible Applications of the Dual Axis Asymmetric SRF Cavities: It has been known that linear and circular accelerator facilities suffer from specific disadvantages, such as, beam energy loss and beam degradation due to synchrotron radiation, or inability to accumulate and re-use the electron bunches. Furthermore, the energy consumption is one of the hurdles, which the next generation colliders and large particle accelerators have to overcome to enable their construction and efficient run. One obvious solution is to use energy recovery in recirculating systems [6,7] to reduce energy losses during beam storage. We argue, the use of

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dual-axis asymmetric SRF structures may solve some of these challenges: minimisation of energy loss and efficient beam recirculation to facilitate energy recover from the beam. A specific example of such system is illustrated in the figure below. It consists of two storage rings (red circles) which accumulate and re-circulate the electron bunches. The bunches are stored at the energies W_0 appropriate to tolerate the energy losses and beam degradation. The rings are then fed by the ERL accelerator (green ellipse) which can be similar to CBETA [8] and also based on dual-axis asymmetric accelerating cavity. The CBETA-like machine may also driven by the ERL-injector/recuperator (blue square). Once the beam quality of electron bunches in the storage rings does not meet the required spec, the beam is being redirected back to CBETA-like ERL (green ellipse) from which it goes to the ERL-recuperator (blue square) and eventually to the beam dump. Finally, the beams from the storage rings are injected into a "Dogbone" ERL [6,7] for further acceleration and energy recovery. The beams are accelerated toward each other in the accelerating structures along the accelerating arms from initial energy, W_0, up to the required energy, W_f, ready to collide at the interaction point. After the collision, both beams are directed and transported through the decelerating arms of the dual-axis structures reducing the beams energies to the required for the storage rings energy W_0. Such a system assures the energy recovery from the beams, recirculation of the bunches and minimisation of the energy beam losses due to synchrotron radiation, as compared to a conventional circular system. The arrows in the figure below indicate the beam travel directions.

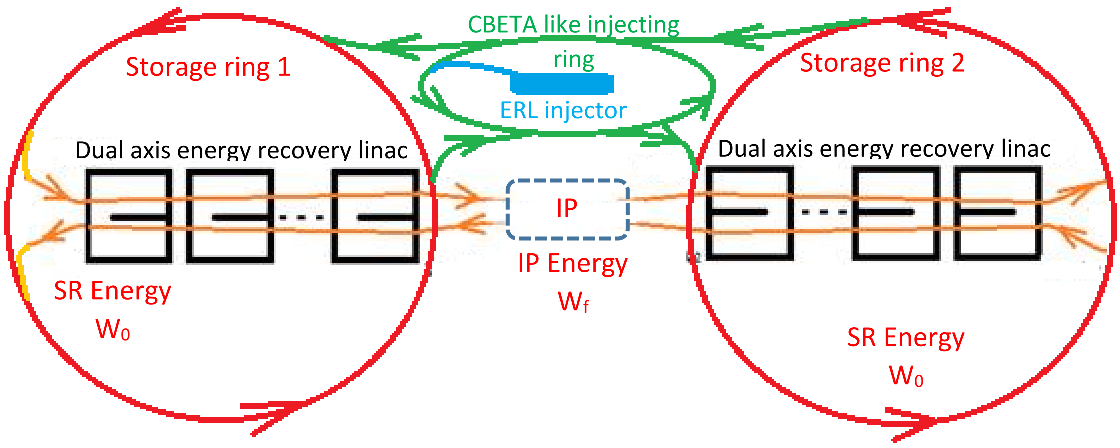

Figure 1. *Schematic of the high-energy electron accelerator based on dual-axis accelerating/decelerating structures. The schematics shows: injecting system (CBETA-like ring and ERL injector) shown in blue and green; storage rings (shown in red colour) and energy boosting/recovery linear accelerating section. In the energy boosting/recovery section the beams trajectories are shown in orange and the interaction point (IP) is presented by a dash line square.*

Conclusions and Outlook: At the current stage, the dual-axis asymmetric cavities have been studied, or considered for research at JLAB (USA), University of Oxford (UK), University of Lancaster (UK), MEPhI (Moscow, Russia). These preliminary studies already have brought promising results. To bring them to the next level, we wish to further stimulate development of this concept. Obviously, this requires endorsement and support from the research community. To start a technology demonstration, one needs to build such a dual-axis cavity, measure its performance and compare it with theoretical predictions. The next step will be to construct and test 1 Amp, 30 MeV ERL based on this. Completion of the first two steps may bring genuine interest from industrial partners, which would significantly 'boost' further deployment.

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