HIGH POWER KLYSTRONS FOR HIGH ENERGY PHYSICS RESEARCH APPLICATIONS

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Klystrons have, due to the adaptability of their basic design concept to a large spread of requirements regarding operating frequency, output power level and modes of operation become the predominant source of microwave power in accelerator and fusion reactor applications. In close cooperation between tube industry and users a spectrum of klystron types covering the frequency range of 200 to 3000 MHz for CW- and pulsed operation has been created to meet these requirements. A selective describtion of the Philips/Valvo activity in this field is given emphasising development issues of CW-types with high unit power and high efficiency.

Design Concepts

The development of high power CW-tubes has profited by 25 years of manufacturing and field experience with UHF-TV-klystrons. Although their RF-output typically is only a small fraction of that of klystrons for accelerator use their basic technologies as related to cathodes, material treatment, joining and processing techniques as well as many design concepts proved a reliable starting position for higher power designs. On the other hand, large dimensions, high operating voltage and power dissipation levels have made necessary new approaches to the design and to manufacturing techniques and have required the development and installation of new production and test facilities. A selective listing of representative tubes types, some in production others still in various phases of development, is given in the table. Common features which are shared by most of the CW-tubes are:

- Impregnated Tungsten Cathodes with high CW-emission capability and stability even under adverse operating conditions. In many tubes, in particular for lower frequencies, only a small fraction of the emission capability of the cathode is used thus adding extra reliability to the design.

- Current Modulation Techniques

  Most klystrons of the data table are equipped with modulation anodes for RF-power control. They are typically operated at DC-potentials of about 50 percent of the beam voltage. Their use, however, is limited to control functions of slow to moderate velocity. For fast control functions gridded guns have been developed (fig. 1) which require low voltage modulators. It is expected, that this technique will obtain increasing importance in future accelerator applications.

- Low Perveance Design. Computer studies as well as experimental results have shown, that lower perveance beams in klystrons yield higher efficiency (with all other parameters optimized). With the predominant role of efficiency in high power tube design the price of an increased operating voltage is generally paid.

- Optimization of RF-Sections. Tube design makes use of sophisticated computer codes for optimization of the buncher and output section, which, for some types includes harmonic bunching for enhancing efficiency.

Valvo Power Klystrons for High-Energy-Physics Application

type	frequency MHz	r.f. power kW	operation	efficiency %	beam voltage kV	tube length cm	status
V 140 SK	208-216	2000	cw	ca. 70	115	ca. 550	dev. study
V 107 SK	324	1500	long pulse (cw)	68	100	400	prototype
YK 1350	352	1100	cw	68	90	400	production
YK 1300	500	600	cw	60	60	350	production
YK 1301	500	800	cw	66	75	350	production
V 143 SK	500	1000	cw	> 68	85	ca. 380	dev. study
YK 1250	1000	400	cw	60	56	250	production
V 141 SK	1000	500	cw	> 60	62	250	dev. study
YK 1240	1300	350	long pulse	52	60	180	production
V 142 SK	1300	400	cw	> 55	62	ca. 220	pre-development
V 139 SK	2380	400	cw	> 50	65	ca. 170	dev. study
V 137 SK	2998	35000	short pulse	> 48	280	175	prototype
V 131 SK	2700-2900	200	long pulse grid-modul.	> 45	38	ca. 150	development

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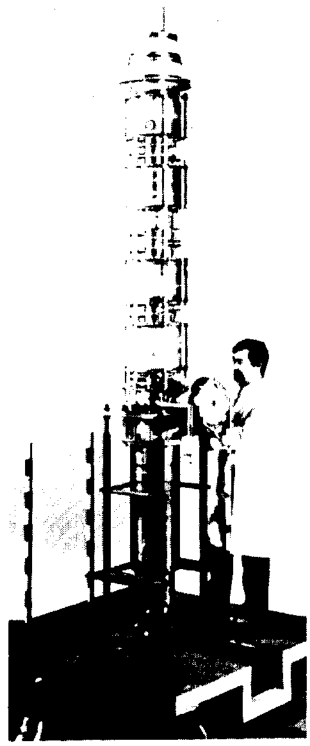

Fig. 1 1.1 MW/352 MHz-klystron YK 1350 during assembly

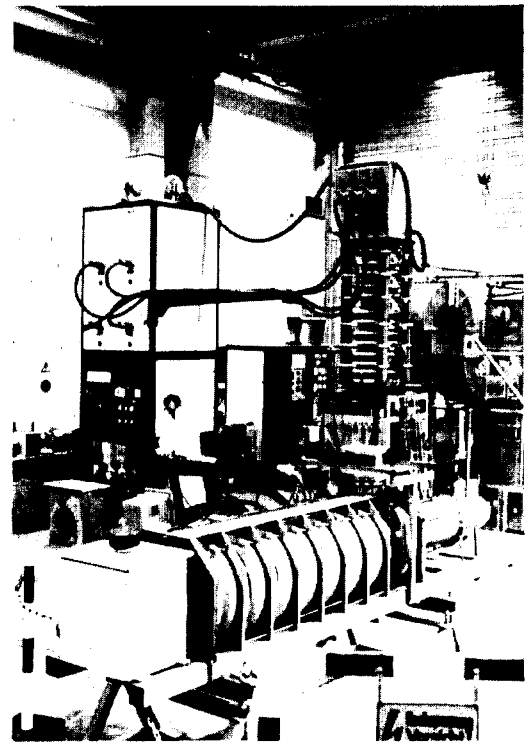

Fig. 2 YK 1350 in laboratory focusing unit (YK 1301 in the background)

For additional empirical optimization all klystrons are equipped with rugged tuning mechanisms for the cavities. External matching elements are provided for several types to match the klystron to a variety of operating conditions with a maximum of efficiency.

- RF-Window. Design concepts vary according to frequency and power level. For UHF- and lower frequencies forced air cooled coaxial windows are used up to power levels of presently 1.5 MW CW without having reached their limitations. Several waveguide window concepts have been developed for higher frequencies with forced air and liquid cooling.

- Collector Design. In a klystron the loading of the collector is heavily affected by the operating conditions with the most unfavourable loading conditions occuring with RF-drive completely turned off. Collectors, which are designed to withstand these operating conditions over an unlimited length of time are correspondingly large and require a coolant flow sufficient to accept the full beam power. Several tubes of the data table are equipped with DC-beam power rated collectors.

  An alternative approach to collector design makes use of the fact that in most accelerator facilities klystron operation without RF-drive will occur only in the event of a fault. In this case the collector design must not take into account the full DC-beam power and smaller collectors requiring less coolant flow can be designed. This design philosophy is generally prefered for high power, low frequency tubes.

Tests of a 1.1 MW CW klystron at 352 MHz

An example of a recent CW-development is that of the 1.1 MW/352 MHz-klystron YK 1350 for use in the LEP-ring of CERN/Geneve. The klystron is constructed for horizontal operation to fit into underground facilities with limited ceiling height. The tube is shown in fig. 1 during assembly from modular subsections. A prototype of this klystron in a laboratory focusing unit, with the output waveguide transition not yet mounted, is shown in fig. 2. (For comparison: a vertically operated 500 MHz-800 kW klystron YK 1301 in the

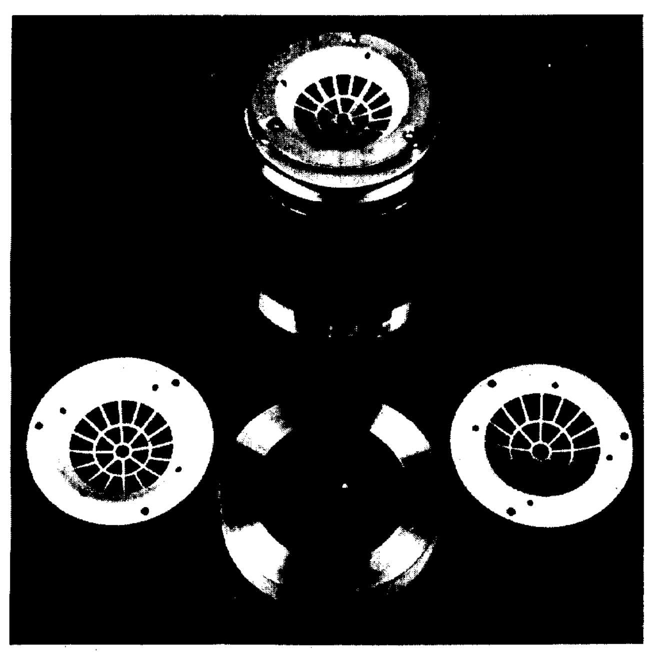

Fig. 3 double grid gun cathode assembly and parts

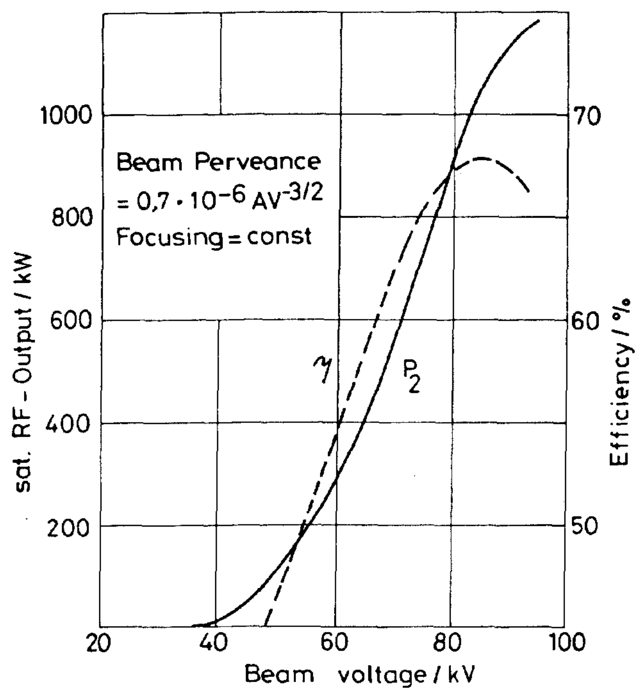

Fig. 4 Saturated RF-output and efficiency of YK 1350

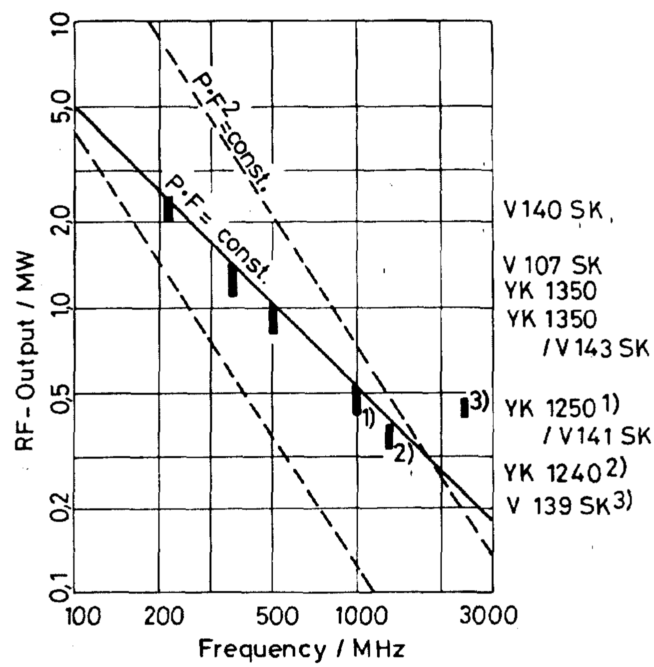

Fig. 5 Scaling laws and some actual klystron designs

background of the 150 kV/40 Amp factory test facility).

The prototype klystron was tested to the full specified RF-power of 1.1 MW. In fig. 4 the saturated output and efficiency are shown as functions of beam voltage. The magnetic focusing field was optimized at 1.1 MW/90 kV and was kept constant. A maximum efficiency of 68 % was achieved in these tests. Since the RF-window is considered a critical tube element at high power levels its performance was carefully tested. From calorimetric measurement total losses of the window section are estimated to remain below 300 W for 1.1 MW transmittered power with the main contribution by the coaxial center conductor rather than by dielectric losses of the window ceramic. The temperature difference across the window is kept below 10 °C by a moderate air flow. Test results are encouraging the use of this window concept even at considerably higher power levels.

Frequency-Scaled CW-Designs

From consideration of the relevant parameters related to losses, electrical fields, characteristics of the cooling circuits etc. is seen that frequency scaling for a fixed design concept may approximately follow a power x (frequency)^2 = constant law. Several such $P \cdot F^2 =$ const. lines are drawn in fig. 5, each of them representing a specific design concept and technological standard.

Many recent klystron developments in the UHF- and SUB-frequency region however follow a $P \cdot F =$ const. line, which seems better to reflect the combined effects of the needs of the market, operational and economical considerations, a certain reluctance with respect to the huge dimensions at low frequencies and the tube engineers ambition to explore the limitation of his design and technology at higher frequencies. Examples of present development activities are two klystrons at the lower and higher end of the considered frequency range. The 200 MHz klystron V140SK with an RF-output of 2 MW presents a design whose challanges are not to be seen in physical and technological limitations, but rather in those design aspects, which are related to large physical dimensions and the operational requirements. On the other hand, high power densities in the 2400 MHz/400 kW klystron V139SK clearly stress the weight of the technological aspects.

There do not seem to exist fundamental restrictions to extend klystron designs to even lower frequencies, a region which today is served exclusively by grid-controlled tubes. However, the dimensions of klystrons will be so large, as to make them attractive only for very high power. Alternative design approaches, such as high perveance hollow beams for reducing the operating voltage and consequently klystron length as well as RF-resonator designs with reduced dimensions are presently being studied.