Production and Reliability of the VKU-8891M Series DBS-MSDC Klystron

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With the development of a four-stage depressed collector for air-cooled, permanent-magnet focused, medium-power klystrons, CPI introduced a new generation of high-efficiency klystrons to the satellite-communications market, covering C-, Ku-, and the direct broadcasting satellite (DBS) band. This paper describes the production and over three years of field experience for the VKU-8891M series klystron serving the DBS market. This klystron was the first to utilize the multistage depressed collector (MSDC) in satellite-communications applications.

The klystron operates at frequencies between 17.3 and 18.4 GHz, up to 85 MHz minimum instantaneous bandwidth, and up to 2.4 kW minimum rf output power. With a saturated efficiency of 40 percent this klystron far surpasses the performance of a conventional klystron. As a result, this technology saves up to 68 percent of the power required by existing products in this market in average field-operating conditions.

The regular production of the VKU-8891M series started in spring of 2000. As of December 2003, a quantity of 277 klystrons has been produced and shipped. With seven klystrons scrapped in production, the production yield amounts to 97.5%. Out of the 277 klystrons in the field, 32 klystrons had to be returned due to various failures. Failure mode and distribution are given in Table 1. Half of the failures were minor repairs, which didn't require the opening of the vacuum envelope. Five of the 16 major repairs were induced by the customer.

Table 1 Reasons for klystron failures.

	Quantity	Failure Type/Location
Minor Repair	4	Internal/External Tuner
	4	Collector Arcing
	3	High Voltage Connector
	2	Low Gain / Retune
	1	Body Current
	1	Reversed Input Isolator
	1	Waveguide Flange Pressure Leak
Major Repair	5	Internal Tuner
	4	Vacuum Leak
	3	Melted Drift tubes *
	2	Broken RF Window *
	1	Premature Gun Failure
	1	Internal Electrical Short

* Customer Induced

The majority of the failures (67%) occurred within the first 100 units produced, i.e. many failures can be attributed to the learning process associated with a new product. This is demonstrated in Figure 1, where amount and severity of failures versus unit number are shown.

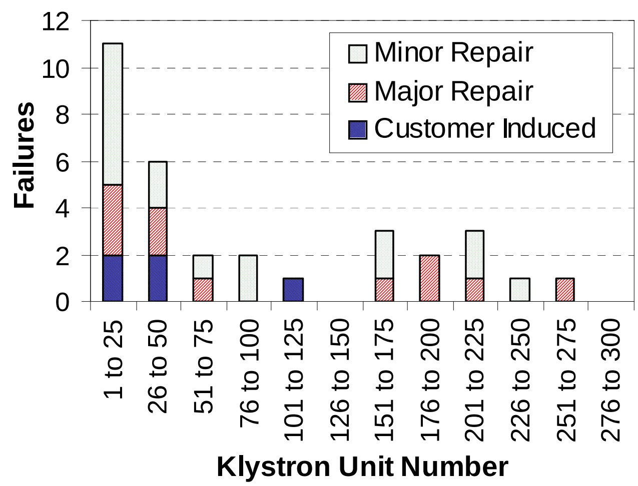

Figure 1 VKU-8891 series klystron failure data.

The operating hours before failure in conjunction with the data from the units still operating in the field can be analyzed using the hazard plotting method for incomplete multiply-censored failure data as described in [1]. In the Weibull-hazard plot the time to failure is plotted against the cumulative hazard in double-logarithmic scale. The cumulative hazard H(t) correlates to the probability F(t) for a unit to fail before a certain amount of time t by

$$F(t) = 1 - e^{-H(t)} . \qquad (1)$$

In this type of failure analysis the data are fitted linearly in the double-logarithmic scale of the Weibull-hazard plot. The time corresponding to a hazard of 100% is considered the characteristic time to failure. The probability for a unit to fail before this time is 63%.

The failure data of the VKU-8891 series are shown in Figure 2 in the form of a Weibull-hazard plot. The operating time of failed units after repair was not considered in the analysis. The graph demonstrates that the data follow – independent of failure category – two distinct straight lines. The higher slope for times above approximately 1500 hours (about two months) indicates that after this time in the field the characteristic time to a klystron failure is considerably higher. The results from evaluating the data for different categories are summarized in Table 2. When taking all the failure data into consideration, the characteristic time to failure amounts to 74,100 hours. The number is as high as 111,400 hours when the customer-induced failures are not considered for the fit; this is represented by the line labeled "Major & Minor" in Figure 2. The characteristic time to failure is considerably higher in all categories if only the failures after 1500 hours are used for the fit. In this case the numbers in all categories are above one million hours.

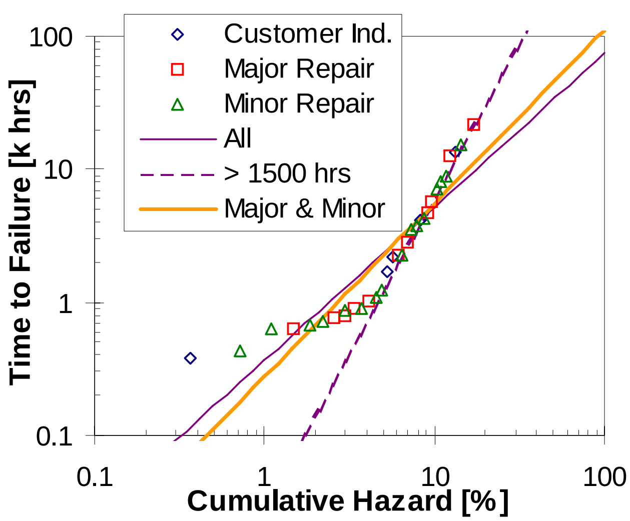

Figure 2 Weibull-hazard plot of VKU-8891 series klystron failure data.

Table 2 Characteristic time to failure derived from different fits of the failure data shown in Figure 2.

[in k hrs]	All Failures	> 1500 hrs
All Categories	74.1	1,308.7
Customer-Induced	35.8	1,052.5
Major & Minor	111.4	1,337.6
Major Repairs	225.0	1,262.0
Minor Repairs	79.8	1,460.1

To date no VKU-8891 series klystron was returned for a "natural" end of the cathode life, which in the absence of other failures would be the only reason to return a klystron for repair. From empirical data this is projected to occur at about 70,000 hours for this type of electron gun. Using the fit parameters for "Major & Minor" repairs above 1500 hours and equation (1), the probability for failure before 70,000 hours is 24%, i.e. 76% of the klystrons are expected to reach the cathode end-of-life. The results demonstrate that proven engineering and manufacturing techniques have been used to establish a mature and successful product.

References

[1] W. Nelson, "Hazard Plotting for Incomplete Failure Data", J. of Quality Technology, Vol. 1, No. 1, pp. 27 (1969)