LONG-TERM OPERATING EXPERIENCE OF LARGE DIAMETER FLEXIBLE COAXIAL CABLE IN HIGH-POWER BROADCASTING STATIONS

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Summary

This paper reviews the operating experience of coaxial cables designed for the transmission of large amounts of high frequency power (with outer diameters up to 12 in.). The cable consists of a welded and corrugated inner conductor, dielectric spacers and a welded and corrugated outer conductor. The major advantage of this design lies in its flexibility and in the fact that it can be produced in long continuous lengths, limited only by the reel capacity. Since the early 1970s over 400 km of this cable have been put into service for broadcast and TV stations operating in frequency ranges up to 900 MHz. Mechanical and electrical design specifications are reviewed and the operating experience analyzed.

Introduction

A review of the high-frequency power of broadcast transmitters over the past several decades shows a steady increase until about 1970. Since then the power output (Table 1) has not increased significantly.

Frequency Range	Max. Transmitter Power
Long wave band (LF) 150 - 285 kHz	2,000 kW carrier power
Broadcast band (MF) 525 - 1605 kHz	1,000 kW carrier power
Short wave band (HF) 5.95 - 26.1 MHz	500 kW carrier power
Television (VHF/UHF) 174 - 960 MHz	2 x 40 kW sync. peak power

Table 1: *High-Frequency Power of the most powerful Broadcast Transmitters around the Year 1970*

The increase in the transmitter power rendered necessary the development of low loss high-power antenna feed cables. A new kind of high-frequency coaxial cable was developed during the 1950s as an outgrowth of the family of power and communications cables, based on the " Wellmantel" (welded and corrugated sheath) technique. The outer conductors (in the case of larger dimensions also the inner conductors) of these cables were fabricated from thin-walled, longitudi nally-welded, corrugated tubes. These new ca ble types started to replace existing, conventional cables as well as cables built from short sections of rigid lines. The latter exhibited the typical disadvantages associated with this type of cable (numerous connections, thermal expansion problems due t o temperature changes, problems with imperviousness, costly installation).

A technology related to the multi section rigid coaxial line concept was recently described in a paper presented at the 1993 IWCS [1]. It deals with a semi flexible high-frequency transmission line built up of many 11.58 m (38 ft.) sections using corrugate d instead of rigid tubes. By contrast, the cable described in this paper can be made in long continuous lengths, limited only by the capacity of the take-up reel at the end of the manufacturing line or by the size restrictions for the transport of the cab l e reel.

For the new cable design a number of technical parameters had to be considered in addition to low attenuation and high structural uniformity to meet the transmission requirements. Other factors, such as thermal problems (losses and heat dissipation) and el ectrical problems (voltage strength, partial discharge, leakage currents) had to be taken into account in increasing measure. Moreover, since the transmission lines were operated at substantial internal pressures, mechanical strength and gas tightness wer e of paramount importance.

To meet these requirements novel approaches had to be developed both with regard to the basic cable design as well as to the materials used and the manufacturing techniques employed. This work culminated about 1970 in the development of a high-power coaxia l cable with an outer diameter of 312 mm (12.28 in.) [2].

An overall consideration was to ensure that the proven long-term reliability of existing cables would be equal to that of the newer high-frequency cables with increased power rating. The reliability of this high-power cable has proven itself in the field: in excess of 400 km (249 miles) in the 6 in., 8 in. and 9 in. die. dimensions have been in operation for the last dozens of years.

A purpose of this paper is to document the long-term behavior of high frequency power cables. A typical case study is represented by the HF9'-S AL cable type at the Wertachtal transmitting Center of the German Telekom. This is a particularly good example b ecause of the unusually large scale of this installation, operating at a very high transmitted power rating which called for a rather unconventional cable design. Last but not least we should mention that this installation has been in operation in excess o f 20 years.

We shall describe the transmitter before presenting the high-frequency cable installation. In so doing we shall dwell in greater detail on the cable for the benefit of the operational experience gained along with the inherent reliability concept on which t his development was based.

The Wertachtal Broadcast Transmitting Center

The Wertachtal Transmitting Center was erected by the German Bundespost during 1969 - 1972 in the foothills of the German Alps, 40 km southwest of Augsburg. This new transmitting center became necessary because the other existing centers of the "German Wel le " (Worldwide Broadcast Service of the German Federal Republic) were no longer adequate.

When it was commissioned, the Wertachtal Transmitting Center included the following ancillary systems:

- 12 shortwave transmitters (5.9-26.1 MHz) with 500 kW carrier power
- 74 antennas, mostly directional curtain antennas with fixtures for shifting the main beam direction by +/-30°
- 53 km (33 miles) type HF9" -S AL high frequency power cable

in addition to an antenna matrix switch unit with 12 inputs and 76 outputs that permitted coupling each transmitter to each antenna. This makes the Wertachtal Center the largest broadcasting center in the Western world. Fig. 1 illustrates the general trans mitting center concept.

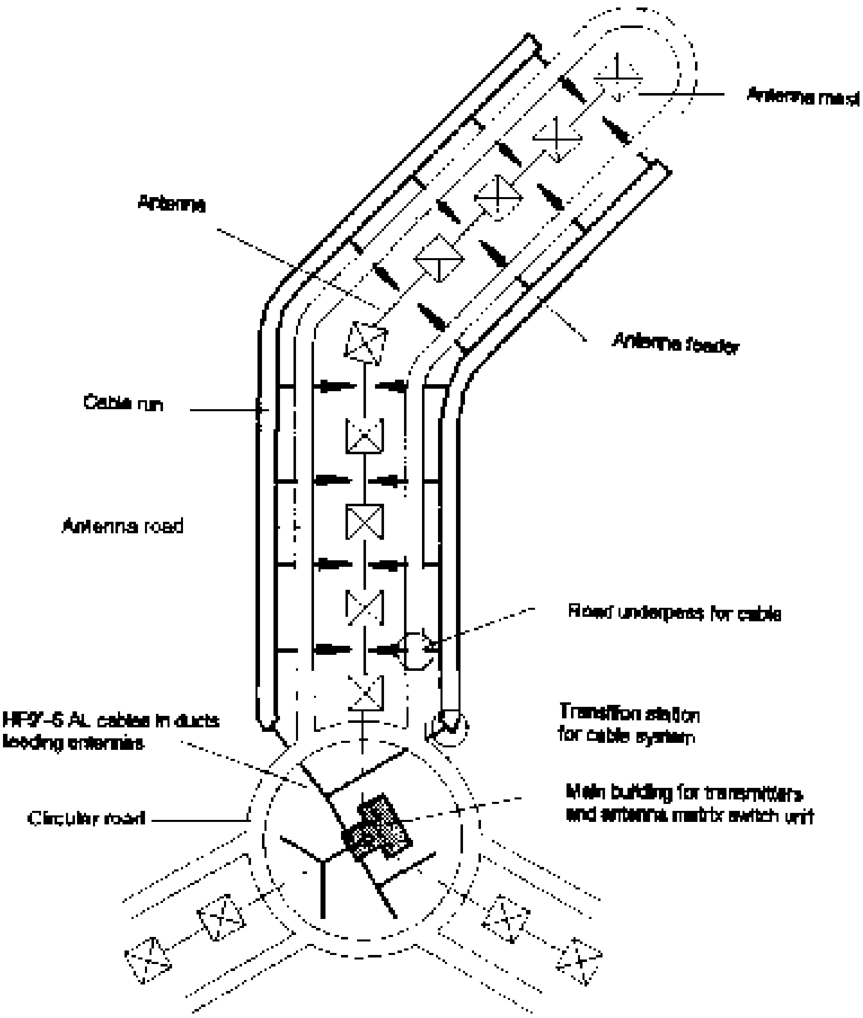

Fig. 1: *Schematic Representation of the Wertachtal Transmitting Center*

The main building is located in the center of the complex. It houses the transmitters and the antenna matrix switch unit. The cables to the individual antennas originate from here.

The antennas are arranged in the field on each side of a three-pointed star. The antenna walls which are located at a 120° angle with respect to each other have a length of about 1.9 km (1.2 miles). They feature a bend along their path (Fig. 1). For a deta iled description of the Wertachtal transmitter we refer to [3].

Properties	Values
Characteristic Impedance	50 +/- 1 ohms
VSWR [1.9 km (1.2 mi.) cable @5.9 - 26.1 MHz]	
Max. Operating Frequency	26.1 MHz
Carrier Power	500 kW
VSWR (Antenna connected)	
continuous	
intermittent	2.2
Modulation factor	
average, continuous	60 %
intermittent	105 %
Max. environmental temperature	35° C

Table 2: *Specified Properties and operational Requirements of the High-Frequency Power Cable*

The High-Frequency Cable System of the Wertachtal Transmitting Center

The High-Frequency Power Cable, its Specifications and Design

The requirements for the high frequency power cable were based on the specified properties and operational requirements of the German Bundespost (Table 2).

The figures given in Table 2 reflect, under worst-case conditions, the following load on the cable:

P(max) = 1,180 kW at V(max) = 21.5 kV

wherein:

P(max) is the average power within a local current peak (a measure of the heat build up in the cable);

V(max) is the peak voltage value at a local voltage maximum with maximum modulation.

(For a description of the general rela tions between cable design, operational conditions and load capacity of high frequency power cables we refer to [2].)

High-frequency cables for such demanding requirements did not exist anywhere at the time. This led to the development of a new, especially designed cable for this project. Foremost consideration during all stages of design, planning, production and install ation of these cables was the goal to achieve for long-term, reliable and failure-free operation.

An important step toward this goal was the decision to avoid, as much as possible, the introduction of components that could become possible sources of failure, such as mechanical contacts and seals. Therefore, a welding technique instead of the convention al clamping technique was implemented. This was also a reason for maintaining the cable diameter as small as possible: the smaller the diameter, the greater the length of cable that could be accommodated on a shipping reel of a given size. In order to enh a nce the heat loss dissipation while maintaining the voltage strength, it became necessary to increase the operating temperature and internal over-pressure of the cable. We selected Teflon as insulating material for the spacer which centers the inner cond uc tor. The material for the outer conductor was a 2.5 mm (.098 in.) thick AlMn strip.

Fig. 2 illustrates the cable design. The three Teflon® support arms of a spacer are mounted on an open metallic spring loaded ring. This feature enabled us to reduce to a strict minimum the quantity of the required insulating material needed for centering the inner conductor.

Fig. 2: *Cable Type HF9"-S AL*

The main technical characteristics of this cable are listed in Table 3.

Cable Design	
Inner Conductor: corrugated copper tube	99 mm (3.9 in.) dia
Spacer material: Teflon	217 mm (8.54 in.) dia
Outer conductor: corrugated aluminium tube	246 mm (9.7 in.) dia
Outer Protection: protective coating (applied after installation)	
Mechanical Properties	
Max. admissible overpressure	5 bar
Max. recommended filling pressure	4 bar
Minimum bending radius	3,000 mm (118 in.)
Electrical Properties	
Characteristic Impedance	50 +/- 0.5 ohms
Attenuation (@26.1 MHz, 20° C)	0.77 dB/km
Max. admissible high-frequency voltage	24 kV (@ 1.0 bar), 42 kV (@ 2.4 bar absolute filling pressure in actual operation
Max. admissible input power	1,230 kW (@ 26.1 MHz/40°C/1.0 bar) 1,600 kW (@26.1 MHz/40°C/2.4 bar)

Table 3: *Technical Characteristics of Cable Type HF9"-S AL*

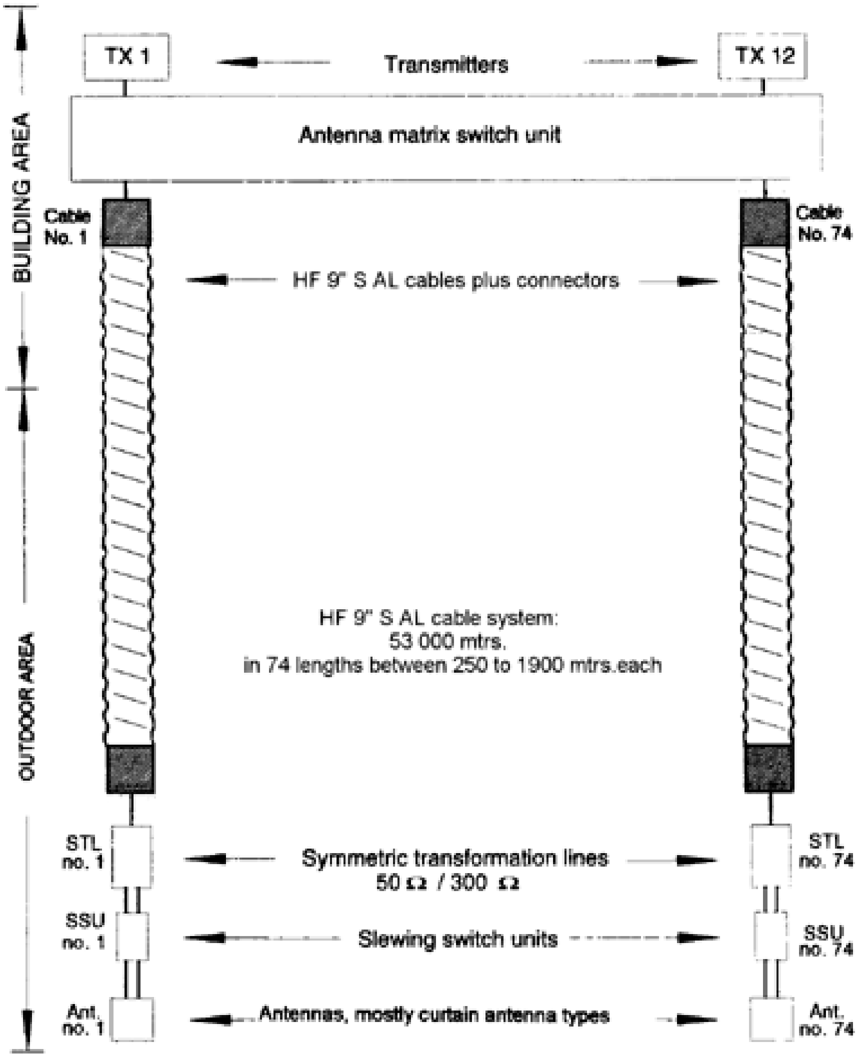

Fig. 3: *Schematic Layout of Wertachtal HF9"-S AL Cable System*

Installation of the High-Frequency Power Cables

The overall cable length of the system at commissioning time was 53 km (33 miles) in individual lengths of 180 m (590 ft.). These were assembled into 74 runs of 1,900 m (6,234 ft.) max. length (Fig. 3). Individual cable lengths were shipped on reels with 3 m (9.84 ft.) core die. and 4.5 m (14.76 ft.) flange die. During installation the inner and outer conductors of adjoining cable sections were welded together in an inert gas atmosphere. Special weld couplings were developed for this application (Fig. 4). T he same welding technique was equally used for the terminations of the 74 individual runs. The only seals required were located at the ceramic spacers of these connectors.

The individual cable runs are routed out of the basement from underneath the antenna matrix switch unit through six underground walk-through channels (Fig. 5) to transition stations. From here on the cables are run outside in parallel, about 0.7 m (2.3 ft.) above ground, on both sides of the antenna walls. They leave the common route, one after the other, in open ducts to terminate at the symmetric transformation lines of their respective antennas (Figs. 5 and 6). Over the length of their exterior run the c ables are covered with concrete plates for protection against icing and direct exposure to the sun.

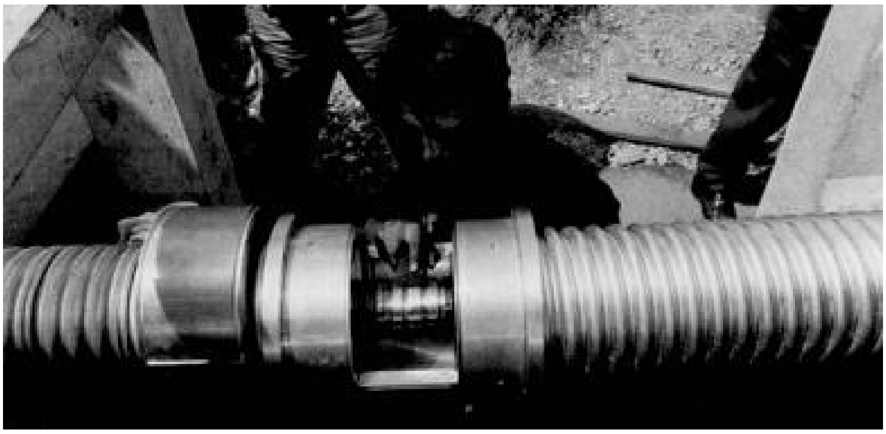

Fig. 4: *View of a cable Coupling for Type HF9"-S AL Cable during Installation*

Fig. 5: *Transition of HF9"-S AL Cables from vertical to horizontal Runs*

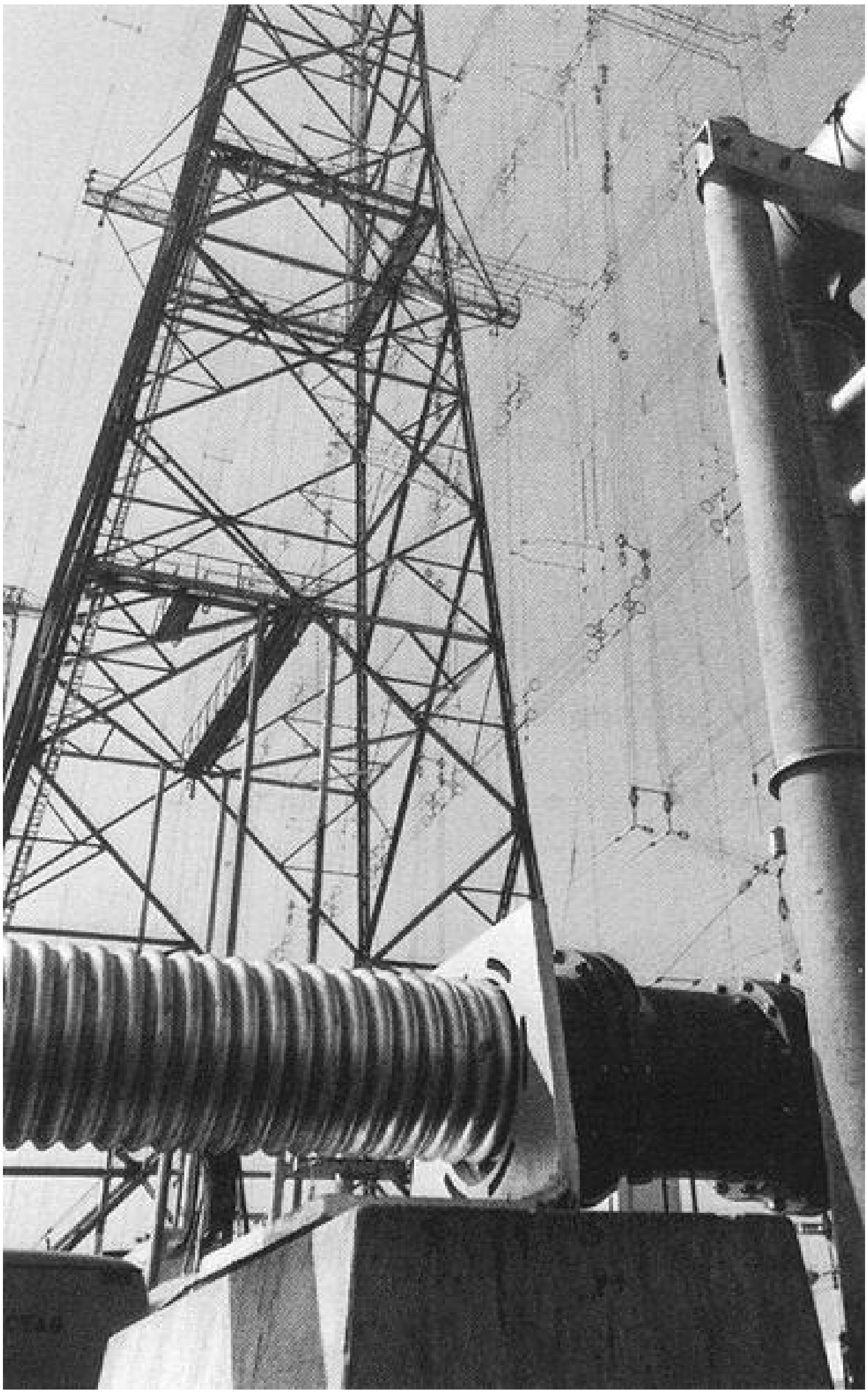

Fig. 6: *HF9"-S AL type Cable connected to Coaxial/Symmetric Transformation Line*

Compressed Air Supply

Dry air is used as the pressurized gas for increasing the power rating and for monitoring the integrity of the cable runs. The compressor is located in the basement under the antenna matrix switch unit. Its capacity is 88 Nm3/h which meets the requirements of the Bundespost: max. 4 hrs. fill time for a 1.5 km (.93 mi.) long cable run.

To ensure the long-term operational life of the cables it is important that all traces of humidity, oil, dust or other foreign matter be reduced to the absolute minimum. This is a significant requirement which was carefully considered in the planning of th e compressor station. Thus, for example, the dew point of the compressed air lies at -40°C. The dew point is monitored by the computer of the station.

Each individual cable run has its own monitor which includes a cut-off valve, a magnetic valve, a flow regulator, a spring-loaded check valve and a safety valve. In case the monitor detects a pressure drop in excess of 0.2 bar with respect to the nominal o perating pressure, it will automatically supply a limited air flow into the cable until the nominal pressure is once again attained.

The incident and its duration are recorded by the station computer so that irregularities that may lead to later problems may be recognized in time. In the event of substantial leakage if the pressure drops even further, the transmitter turns itself off on ce the minimum required pressure is reached. It is possible to bypass the flow regulator for the purpose of a rapid fill.

Operating Experience

The Wertachtal Transmitting Center has already exceeded two decades of operation. This corresponds to the equivalent expected life time of a cable. What can we say about the behavior of the cables? The following influences and properties which are signific ant for the long-term reliability, such as fatigue or aging effects, will be considered:

- Overall operating time
- Mechanical and thermal load factors; - Corrosion
- VSWR
- Voltage strength
- Attenuation
- Gas tightness
- External factors, miscellaneous effect

Overall Operating Time

Table 4 reflects excerpts from the statistics for the years 1993/94 of the broadcast station. These may be considered to be representative for the total operating life.

Mechanical and Thermal Load Factors

We describe here the basic load factor which is modulated by a variable load factor (as a function of operating cycles and environmental temperature variations). This is particularly important for the effect of the internal over-pressure on the weld seams in the cables and on the spacers in the connectors that terminate the individual cable runs. No destructive changes to these parts have been noticed. The effects on the leak rate are described further below.

Operating Experience per Cable Run (over a 22-yr. Period)	Minimum	Average	Maximum
Operating time (years)	0.6	4.1	16.6
Switching frequency (cycles)	8,000	21,700	56,200

Table 4: *Operating Statistics of Cable Runs, excerpted from the Operating Records of the Wertachtal Transmitting Center*

The spacers are subjected to temperature cycling. It is possible for the surface temperature of the inner conductor to reach 140°C. Any change of the Teflon® spacers due to aging which could result in the inability of the springs to maintain their concentr ic position could have serious consequences (voltage breakdown - see further down).

An additional mechanical load is exerted on those of the approx. 200,000 spacers which are located in cable bends. These must resist radial forces in order to maintain the inner conductor in its centered position. Any weakening of the insulating spacers un der the effect of these forces would cause the inner conductor to approach the outer conductor, risking a short-circuit.

Finally, it is possible for the outer surface of the cable to rub against its retainers (i.e.: clamps) in such fashion that the protective coating may locally be rubbed off. This could lead to corrosion of the aluminum outer conductor.

Corrosion

Aluminum which is exposed to the elements without protection will corrode. For this reason (and for improved heat exchange) all cables have been covered with a double layer of protective coating. The externally-located part of a cable run which was exposed to the elements revealed weathering and peeling off of the coating. A new coating will be applied. We did not observe any corrosion damage to the outer conductors.

VSWR

Changes in the geometry of the cable (conductor warpage, shifting of the spacers, excursion of the inner conductors from their centered position in cable bends) affect the characteristic impedance and VSWR of the cable. The VSWR of the cable runs was measu red prior to commissioning. A typical example of the VSWR in the 5.9 to 26.1 MHz frequency range is shown in the acceptance test report of a long cable run (Fig. 7).

In principle, it is possible to establish any changes in VSWR through a renewed measurement. Since there was no reason up to now to go through this trouble (the cables would have to be disconnected at both ends) these data are not available. On the other h and, we can state that during operation the monitoringw of the VSWR of the cables connected to the antennas have not revealed any abnormalities that could have pointed to changes in the cables. We therefore draw the conclusion that no noticeable variation of the characteristic impedance in the cables has occurred.

Voltage Strength

Maintaining the voltage strength is of particular importance for the operational safety of the transmitter. Should a flash-over occur during operation, the cable would certainly be destroyed in the vicinity of the flash over point, requiring the replacemen t of a short cable section.

The individual cable runs were tested prior to commissioning with 1 bar pressure at 40 kV DC. This corresponds to about twice the value of V(max), the peak value of the highest expected voltage stress. The pressure during operation is 2.4 bar. This permits an increase of the allowable operating voltage by a factor of 1.75 (Table 3). We therefore achieve a safety factor of about 2 with respect to V(max).

According to reports from the operating staff, the system has not experienced any flash-over in a cable up to this time. Also, no defects in a cable have been detected nor has there been any flash-over in a cable as a result of emergency shutdowns followin g arc-avers in an antenna - a potential cause for voltage surges.

This positive experience confirms the validity of the design, considered rather revolutionary at the time, which called for the inclusion of a metallic spring within the high-voltage field between two conductors to connect the three support elements of a s pacer.

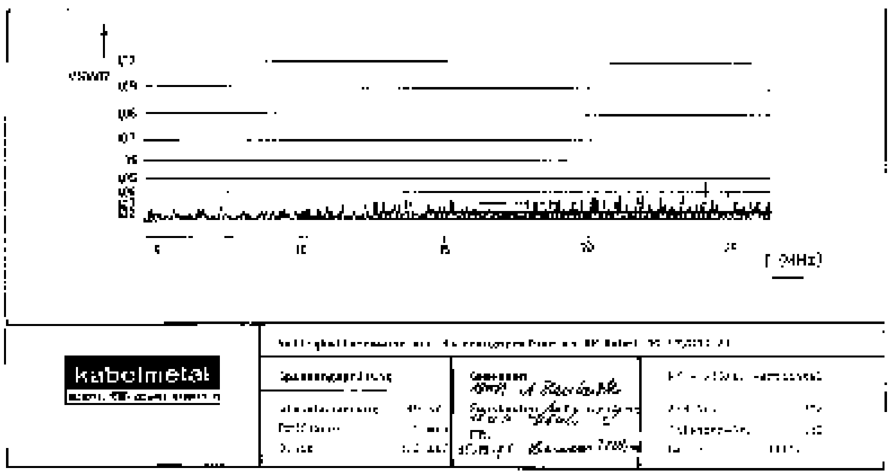

Fig. 7: *VSWR Measurement and High Voltage Test on a Type HF9"-S AL Cable*

Attenuation

Increased attenuation would be indicative of aging of the insulation material of the spacers. The only information available for attenuation is the result of prototype testing. No additional measurements were made. We therefore have no further data.

Gas tightness

Complete and permanent gas tightness of the cables was a basic consideration for setting pressure level thresholds in the monitors. The following events are programmed:

- transmitter power interruption
- gas backfeed occurrence
- gas backfeed interruption
- max. operating pressure occurrence
- safety valve actuation

The pressure levels are attuned to each other in such a fashion that the safety valves will not actuate or that the pressure drop will reach a level that will cause the transmitter to be disconnected, even under extreme conditions. Any and all noticeable a ir consumption is a reliable indicator of leakage under these conditions. According to the transmitter operating staff, no consumption of air due to leakage has ever been recorded in their entire operating experience.

Of course, repeated demands are made on the compressor unit during maintenance and repair work. This requires dis connecting cable runs with subsequent rinsing and filling. Another occasion was the enlargement of the transmitter facility in 1990. During th e course of this kind of activity which required separating the connection between cable and STL (Fig. 6) we noticed, in a few cases, minor damage to the spacer disks in the connectors. We assume that this was the result of the mentioned intervention and w e replaced the spacer disks as a precautionary measure. Of course, this required bleeding the air in the cables and refilling them.

External Factors, Miscellaneous Effects

There were only two incidents during the entire operational life of this installation, as far as we could determine, in which cables were damaged during construction work. In one case, a concrete plate, while being raised, fell on a cable. This caused the outer conductor to be deformed to the point where repair became necessary. For the repair the cable was cut at the point of failure and both ends were joined with a welded coupling. Provided that the required tools, spare parts and expert technical personn el are on hand, this kind of repair can be carried out in one day.

In the second case, several adjoining cables were damaged by a backhoe. The resulting damage, however, was less severe than in the first case. Repair of the damage was not necessary; the cables continue in operation.

Conclusion

The advent of broadcast transmitters with ever-increasing power throughout the world required the availability of high frequency cables of increased dimension and higher load capacity for feeding the transmitting antennas. This development was essentially concluded in the years after 1970.

After two decades of operating experience with this unique design combining features of communications and high-voltage cables, it is instructive to review the performance record of the cables. The Wertachtal Broadcast Station of German Telekom is a perfec t test case for this purpose.

The Wertachtal transmitter was commissioned in 1972 with 12 ea. 500 kW short-wave stations, 74 antennas connected by 53 km (33 mi .) of the type HF9"-S AL high-frequency power cable. This paper reports on the considerations given to the design and planni ng of the cable system with a view to operational safety and long-term operating reliability and how these factors have proven themselves over the years.

The information gained from this large-scale installation confirms its reliability and the soundness of the cable design meeting all technical and maintenance requirements. The installation continues to function properly. There is no end in sight for the e conomic and technical viability of the system. Here is a rare instance in cable technology where a high-power high-frequency cable developed in the 1970s still today represents the state-of-the-art.

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Remark

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