RF STRUCTURE: FABRICATION AND CONDITIONING

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Some key issues in the fabrication of RF accelerating cavities are described in this lecture. In order to discuss those issues, two extremes are presented: a continuous-wave standing-wave cavity for storage-ring use, and a pulsed-wave traveling-wave structure for linear-accelerator use. Simple and tedious but very important issues, tuning the cavity frequency and minimizing the RF loss, are discussed in detail. Some characteristics appearing in the conditioning stage are then presented to show the significant influence of cleanness in the fabrication stage on performance in high field operation.

1 Introduction

The only currently available method of accelerating charged particles to a very high energy is to apply an RF electric field to them in an RF cavity. This RF cavity, or RF accelerating structure, is a device in which an electro-magnetic field is confined in space and time to produce an accelerating mode synchronized to the beam. A single-cell cavity is schematically shown in Fig. 1. The RF power is fed through the input coupler to the cavity, which is tuned in frequency by a tuner. The power is stored in the cavity up to a field that balances input power and power loss. Then the electric field component parallel to the beam direction accelerates the beam.

This accelerating cavity should have the following features. (1) In order to synchronize the accelerating field to the beam for enough time and space, the frequency of the accelerating mode and its phase velocity should be well tuned. (2) In addition, the accelerating field should be reasonably high so that the space necessary for acceleration is within a practical size and the beam instability is kept below a tolerable level. The construction details of RF structures that satisfy these requirements are the main topics of this lecture.

To describe the fabrication and subsequent conditioning of RF accelerating cavities, we present two types of simple accelerating cavities for high energy electrons (see Table 1). In these examples, the accelerated particles pass through the cavity at the velocity of light and therefore no frequency shift of the cavity is needed except for compensation against beam-induced reactance. These cavities are simple examples among a variety of cavities, but they serve to illustrate many important issues in the fabrication and conditioning of RF accelerating structures.

The cavity is conditioned after fabrication. Conditioning means training the cavity by increasing the input power gradually so that the cavity is operated stably after reaching a design accelerating field. Much evidence has been found showing that

the way a cavity is fabricated is related to its performance in high power operation. In the last part of this paper we give examples of conditioning and discuss related issues in the fabrication stage.

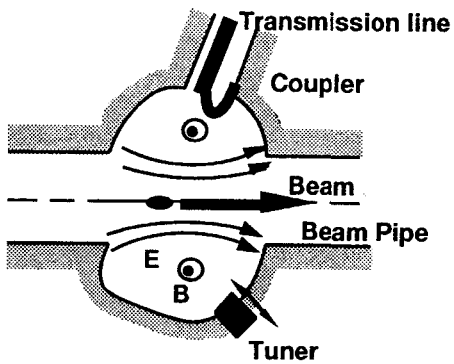


Figure 1. Schematic of a simple single-cell cavity.

Table 1. Typical parameters of two sample cavities; APS=alternating periodic structure, DS=detuned structure. (CW=continuous wave; SW=standing wave; TW=traveling wave.)

cavity	APS	DS
frequency	508 MHz	11.4 GHz
cell diameter	~ 0.5 m	~ 0.02 m
cavity length	2.7 m	1.3 m
number of cells	9	150
application	storage ring	linac
field type	SW	TW
duty	CW	pulsed
average power	150 kW	3 kW
peak power	150 kW	130 MW
coupling between cells	bi-periodic on-axis	on-axis
coupling	5%	2~10%
tuning	with tuner	no tuner
HOM freq. distribution	among structures	among cells & structures
alignment requirement	~ 0.1 mm	~ a few μm

The two examples here are the Alternating Periodic Structure (APS) [1] cavity for TRISTAN and the Detuned Structure (DS) [2] for the main linac of the linear

collider, in both of which the author has been involved. These examples are two extremes of cavity type, in the scale and the electric field characteristics. The former is a typical example of standing-wave (SW) cavity for storage rings at a relatively lower frequency of 500 MHz; the latter is a traveling-wave (TW) cavity for linear accelerators at a higher frequency of 11 GHz. Table 1 lists various typical parameters of the two structures.

2 Requirements

Some of the cavity performance requirements for a high energy electron accelerator are listed below.

1. Good vacuum
2. High electric field
3. Frequency tuning
4. Alignment with respect to the beam

Item 1 is required especially for storage-ring application but is almost always required for stable high power operation in any case. Item 2 is the very reason for the RF cavity with high Q factor. Item 3 is needed for successive accelerations and sometimes for suppressing beam instability by detuning of higher modes. Finally, item 4 is essential to accelerate the beam without serious instabilities. The rest of this paper is devoted to the discussion of various fabrication details in view of these issues.

3 Fabrication procedures

Figure 2 shows interrelation among design, fabrication, conditioning and operation. Figure 3 shows a typical stream of the design, fabrication, and conditioning for accelerating structures. The basic concerns in each process will be described in the following sections with the above two types of structures as examples.

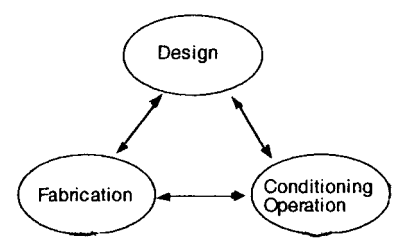


Fig. 2 Interrelation among design, fabrication, conditioning and operation.

Required characteristics
↓
Electrical design
↓
Mechanical and thermal design
↓
Material choice
↓
Machining (rough & fine) of unparts
↓
Surface treatment
↓
Assembly
↓
Bonding
↓
Tuning
↓
Pre-processing
↓
High power conditioning
↓
Conditioning with beam
↓
Routine operation

Fig. 3 Flow of RF structure fabrication from design to operation.

4 Electrical design considerations

4.1 Frequency

The most important parameter is the resonant frequency of the cavity. The cavit should be constructed to make its resonant frequency meet the operation frequency Otherwise the beam cannot be accelerated in many turns in a circular machine c cannot be accelerated constantly in a linear accelerator. Thus it is easy to understan the importance of this, but its accurate realization in practice is difficult, thoug essential, for RF structures.

The frequency of a single-cavity is simply the resonant frequency of the cell. That of a multi-cell cavity with very large coupling between cells is the frequency of the cavity as a whole.

On the other hand, in a r-cell SW cavity with moderate or low coupling between the cells, such as the DS cavity, the frequency as a whole is determined from the average of cell frequencies weighted by the stored energy of the cell. In addition to the frequency itself, cell-to-cell frequency error results in degradation of the uniformity of the field along the structure. This might cause problems, such as a local excess in heat dissipation or a breakdown due to a local high field.

In a TW cavity, like DS, the cell-frequency error results in phase slip of the beam in the cell. If the frequency error is systematically shifted, the integrated phase slip along the structure becomes big. However, if the error is random from cell to cell, the effect is not cumulative and does not degrade the acceleration characteristics.

Even if the random error is not serious for acceleration purposes, it might cause beam instability due to higher modes. If the frequency distribution is designed to make a coherent cancellation among higher modes, the random error is worse than a systematic error.

4.2 R / Q

The R/Q value, which is given

$$\frac{R}{Q} = \frac{V^2}{\omega U},$$

represents the effectiveness of transfer of the RF energy into the beam, with U the energy stored in the cavity, V the cavity voltage. This is determined only by the geometrical shape of the cavity, though it is not very sensitive to the shape, because it is usually optimized to be maximum to make the energy transfer efficiency high. However, in case that this value for some higher mode is designed to be canceled out with a cavity, it becomes sensitive to the shape and is perturbed even by a very small perturbation to the cavity wall.

4.3 Q value

The decrease of the energy stored in an RF cavity is characterized by the Q value. The loaded Q value, Q_L, which includes all the mechanisms is expressed as

$$Q_L = \frac{\omega U}{P_{wall} + P_{external} + P_{beam} + P_{lossy} + P_{contact}}$$

where subscripts for various power losses are as follows; wall = wall current loss in a cavity inner surface, ex = external coupling toward outside cavity, beam = beam loading, lossy = loss into some lossy material in the cavity, and contact = loss related to the imperfect current flow between the parts comprising the cavity. In order to make the efficiency of transmitting the RF energy into beam acceleration, this Q value should be as high as possible for a given cavity shape. Note that to establish a high Q value, a basic measure is to study various fabrication techniques and check the Q value.

On the other hand, for higher modes that perturb the beam stability, the Q values are usually designed to be low. This is because the coupling impedance of the mode to the beam is written as

$$R_{coupling} = \frac{R}{Q} \cdot Q_L,$$

and a lower Q value will give a lower impedance if the shape of the cavity is kept the same and therefore the R/Q value is the same. Lowering the Q value can be accomplished by such coupling devices as a loop or an antenna to obtain P_{ex} or by coating a part of the cavity surface with lossy material to increase P_{wall}[3].

4.4 Coupler

The coupler is a part of the cavity where the RF power transmitted through the transmission line is converted to feed the cavity. One of the important issues is to match the coupling between the transmission line and the cavity. Otherwise the input power is largely reflected back. A mismatch not only lowers the efficiency but also sometimes destroys high power components due to a large standing-wave ratio.

Separation of the cavity vacuum from the outside is usually done at the coupler by using a ceramic. The ceramic is easily broken by such mechanisms as multipacting, a large discharge, continuous pitting, or thermal stress. Therefore, the electrical and mechanical design to counteract these effects is very important in designing the coupler. One of the basic ways is to minimize local enhancement of the electric field inside a coupler. Another usual way is to coat the ceramic with material such as TiN to reduce multipacting, discharge, and electrical charge-up.

4.5 Tuner

The frequency of the whole cavity or sometimes even a part of the cavity system should be tuned when the operating condition changes due to the input RF power or

the beam condition. This is done by changing the geometry of the inner surface of the cavity.

The most straightforward way is to introduce a movable tuner which forms an inner conductor of a coaxial line. The opening into the cavity is preferably designed to be electrically shorted by a mechanism such as a mechanical sliding contact or an imaginal short using a choke circuit to reflect the RF field back to the cavity while keeping the capability of mechanical motion. Moreover, the introduction of the high power of the accelerating mode into the tuner body is prevented by using the mirror symmetry of the field so that no coaxial mode is excited. However, various higher modes in the cavity have different frequencies and field patterns so that some beam-excited modes can be coupled into the tuner body. Since a cavity with beam is affected by this leakage power, it is necessary to perform conditioning with beam if a problem such as vacuum increase or discharge in the tuner is serious. Actually the tuners for the APS cavities were trained after installation into the ring because of the impact of the power due to the beam-excited TM_{011} mode.

5 Mechanical and thermal design

The list of various mechanical parameters of the two cavities in Table 2 shows that the two cavities have different scales and different precisions. These differences require different mechanical and thermal designs, which can be realized by technically different methods of fabrication.

Table 2. Comparison between two structures' mechanical and thermal features.

cavity	APS	DS
frequency	508 MHz	11.4 GHz
scale	0.5 m	2 cm
base material	iron	oxygen-free copper
alignment requirement	0.1 mm	a few μm
alignment mechanism	self-fitting	outer diameter
HOM frequency control	2×10^{-4}	$< 10^{-4}$
surface	Cu plating	diamond cut
joining method	welding	diffusion bonding
contact	edge with pressure	diffusion
vacuum seal	welding	diffusion
mass production	10^3 cells	10^6 cells

Because the scale is large in a low frequency cavity such as APS, copper-coated iron was used for mechanical strength and low price. The parts can be welded to

obtain the necessary mechanical strength, alignment precision, and vacuum tightness. On the other hand, the precision necessary for a high-frequency structure such as DS is very high and this requires ultra-precise machining of the cells with a diamond tool. Today's high-precision techniques can be applied to cells up to 10 cm in diameter. The parts are bonded to maintain the precision of the machining. The diffusion-bonding technique is used to prevent slippage between the cells and suppress deformation of the cell. It should be noted that it is very difficult to realize the needed tight tolerance with a self-fitting mechanism.

The heat is usually removed by water. It is preferable to design a cooling channel not connected to the cavity vacuum through any bonding plane. This prevents vacuum leakage from a water channel even after operating for many years. On the other hand, the pass length from the water channel to the cavity surface should be thermally short. Copper is preferred to iron or stainless steel because of its high thermal conductivity.

6 Fabrication in practice

Care must be taken during fabrication to realize the desired cavity performance, mentioned above. In the following, two areas that require care are described in detail: frequency tuning and Q-value-related issues.

6.1 Frequency calculation and determination of dimensions

The frequency of a simple cavity can be calculated precisely with numerous numerical solvers such as YAP[4], PISCES-II[5], GOOFEE[6], etc. However, it is sometimes still necessary to determine it experimentally to finalize the mechanical dimensions, because the dimension specification is better than 10^{-4} (relative) and it is difficult to realize such accuracy even with the present high precision machining technique. However, this technique offers a way of precisely controlling some typical dimensions with respect to a reference that is machined in the same way. The experimental determination serves to provide such a reference point.

In addition, the assembly process involves various perturbations from the bonding process such as non-uniform pressure and stress sometimes at high temperature, a liquid phase between parts, local welding, etc. However, once one of the typical cases has been experimentally determined as a reference, all similar cases with moderate differences in dimensions can be precisely reproduced with present-day high precision fabrication.

6.2 Frequency measurement

The frequency of the cells or the whole cavity is a most important parameter and should be measured precisely. This section describes the measurement technique in detail.

Usually the measurement is performed in air and therefore the dielectric constant of air should be taken into account. A practical formula for the relative dielectric constant k_ε is given by Montgomery [7] as

$$k_\varepsilon = 1 + 210 \cdot 10^{-6} \frac{P_a}{T} + 180 \cdot 10^{-6} \left(1 + \frac{5580}{T}\right) \frac{P_w}{T},$$

where P_a and P_w are the partial pressure of air and water, and T the absolute temperature. However, it is not clear whether the atmosphere inside the cavity is the same as that outside the cavity. To avoid this uncertainty, the cavity is frequently filled with nitrogen gas, for which the dielectric constant is simply determined for 1 atm at 20 °C as

$$k_\varepsilon = 1 + 5.47 \cdot 10^{-4},$$

and the atomospheric pressure and temperature can be measured precisely. It is worth noting that the frequency change due to deformation through the evacuation process should be estimated or measured.

On the other hand, consideration of the cavity body temperature is simple if the temperature distribution is uniform. In the case of copper at room temperature, the thermal expansion coefficient is simply

$$\alpha = 1.65 \cdot 10^{-5}.$$

Another important consideration is whether or not parts such as tuner or coupler are present. The effect of these parts is usually difficult to estimate precisely and should be measured in advance.

6.3 Frequency measurement in a multi-cell cavity

In order to evaluate the basic dimensions of a multi-cell cavity, it is reasonable to sandwich those regular cells with given half end cells, as shown in Fig. 4. If the resonant frequencies are measured over the entire passband, we can evaluate the resonant frequency of the mode of interest. In this case, however, the effects of the end cells are difficult to estimate and therefore the value obtained suffers from the ambiguity of the end-cell estimation. Even so, this technique can be used if the

number of cells, N - 1, is very large, where the effect of the end cells is negligibly small. On the other hand, if the measured frequencies are plotted as a function of the number of regular cells, as in Fig. 4, the frequency in a periodic condition f_r can be accurately evaluated from the measured frequency f_m by extrapolating to the point N = ∞ as described in the following formula,

$$f_m = \frac{\sum u_r f_r + \sum u_e f_e}{\sum u_r + \sum u_e} = f_r + \frac{f_e}{N},$$

where (f_m - f_r) is the measurement error, f_e the frequency of end cell, u_r the stored energy in a regular cell and u_e that in an end cell. This technique is used for determining a reference dimension.

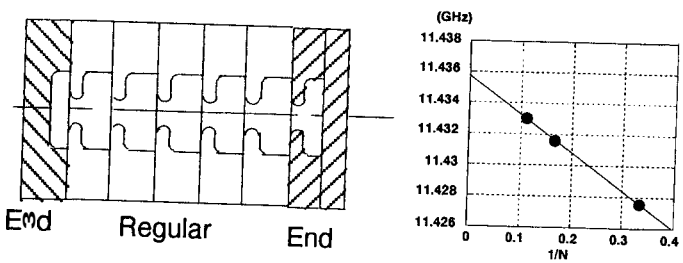


Fig. 4 Configuration for measuring the basic frequency in a periodic boundary condition. LEFT shows the case of N=6. 1/N plot for identical regular cells with N=3, 6, and 9 to evaluate the frequency in a periodic condition.

The cell frequencies can be measured even after construction. One of the methods is to measure the frequency of the resonant mode excited within two detuned cells. The termination of the field of the mode can be established by detuning the two cells by inserting two plungers from the two ends, as shown in Fig. 5 (SW). In this configuration, the 1/N plot to analyze the measurement described above can be applied for a constant-impedance case in the same way. However, the termination of the field depends on the detailed configuration of plunger and cell, and then the measurement suffers from some ambiguities due to this effect in the case of non-constant impedance.

The same technique to detune a cell can be utilized to measure the reflection coefficient as a function of cell detuning, as shown in Fig. 5 (Nodal shift). This reflected phase can be analyzed as the integrated round-trip phase along the structure and can be converted to information about the frequency of each cell. This technique

is called the "Nodal-shift" method. As the measurement is performed through a coupler cell, the mismatch there causes a non-ideal pattern of the reflection coefficient as a function of cell number. This mismatch can be estimated however by assuming uniformity within three successive cells[8]. An example of this type of measurement for a 150-cell DS is shown in Fig. 6 (Nodal-shift measurement). Each point represents the reflection coefficient, S_{11}, of the traveling wave reflected back at each cell. The successive data are 240° apart. As seen in the figure, the detuning condition varies greatly as the plunger-to-cell geometry changes, especially near the input coupler region where the diameter of the plunger is much smaller than the beam hole aperture. The attenuation can also be evaluated in addition to the phase information.

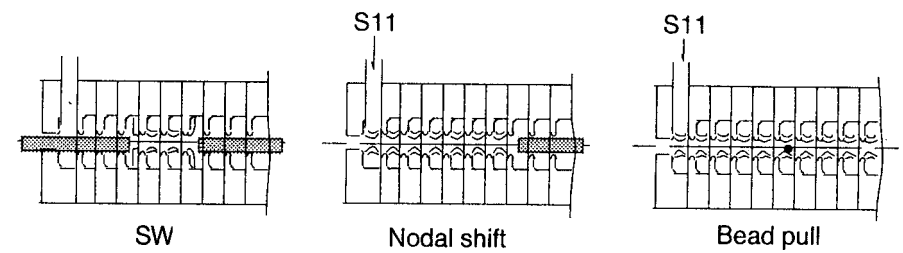


Fig. 5. Cross-sectional views of three methods of measuring cell frequencies. LEFT: Standing wave between two plungers. CENTER: Nodal-shift method, measuring the reflection coefficient. RIGHT: Non-resonant bead perturbation method using a small bead as a perturbing device.

In order to get rid of this varying detuning condition at the reflection cell, a small perturbation by a ball or needle, called a bead, is utilized to cause a reflection of the traveling wave, as shown in Fig. 5 (Bead pull). This technique is called "Non-resonant perturbation"[9]. A sample measurement on the same structure is shown in Fig. 6 (Bead-pull measurement)[10]. The center of the three leaves in the reflection is the mismatch due to the input coupler. The measurement around this center is 240°/cell, showing the right phase advance. The field amplitude can also be estimated from these data. It should be noted that, as anticipated, no spurious phase shift due to the measurement system, which depends on the position of the bead, is observed.

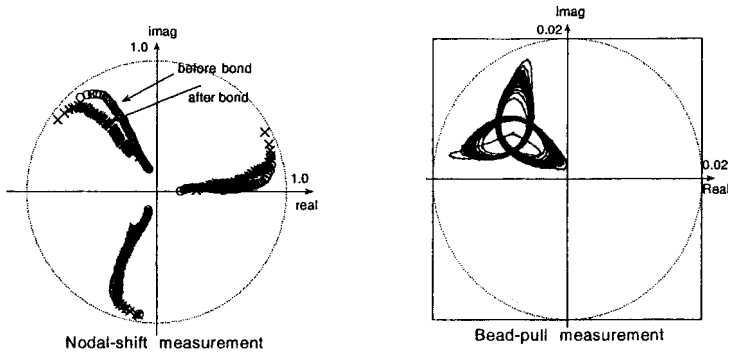


Fig. 6 Measurement of cell frequencies of a 150-cell detuned structure as function of cell number. LEFT: Nodal shift before and after the bonding process during fabrication. Each point represents the reflection coefficient due to the reflection at each cell. RIGHT: Bead pulling after completion of fabrication. Data points were measured in fixed steps along the structure.

6.4 Frequency tuning

From Slater's perturbation theory the frequency change is expressed as [11]

$$\frac{\delta\omega}{\omega}=\frac{1}{2}\int(H^2-E^2)\,dV \quad \text{where} \quad \int H^2\,dV=\int E^2\,dV=1.$$

In order to tune the frequency of a cavity, its inner surface is perturbed. A SW cavity is usually equipped with a movable tuner for this purpose. The tuner can compensate such mechanisms as fabrication errors and thermal distortions. It can tune the cavity even during operation, though the speed of tuning is limited by its mechanical movement.

If this mechanical tuning is not applicable, in cases such as a multi-cell TW structure, fabrication should be high-precision or tuning such as dimple tuning, in which the cell wall is mechanically deformed by local dimpling either inwards or outerwards, should be applied. In order to tune a cell of X-band structure by $\delta f/f = 10^{-4}$, equivalent to tuning a cavity radius of 10 mm by 1 μm, it is necessary to make a cone 0.1 mm high with a radius of 2 mm. Since this dimpling is fairly large, this deformation cannot be performed at a position of high electric field, which makes the frequency decrease, in contrast to the usual case of dimpling in the area with a high magnetic field where the frequency is increased by pushing from outside.

In order to decrease the frequency, another method is to pull at the position of high magnetic field to produce a dimple concave within the cavity.

6.5 Q-value-related issues

The Q value serves as a good measure of various qualities of the cavity. It can be used in the study of various mechanisms or in checking during fabrication, as described in the following.

6.5.1 Electrical contact between parts

Electrical contact between parts is very important for stable cavity operation. This is reflected in $P_{contact}$.

Each cell in the APS cavity is composed of two parts connected at an edge, as shown in Figure 7. The Q value was measured as a function of contact pressure. As shown in the figure, the Q value saturates with contact pressure above 50 kg/cm, indicating that the loss due to the contact becomes small enough above this pressure. The practical pressure, however, was determined to be 200 kg/cm, where the frequency of the cell is almost saturated.

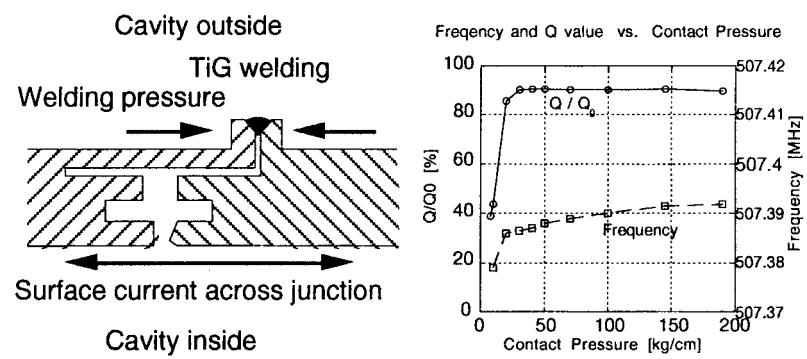


Fig. 7 Left: Schematic drawing of the edge contact between parts for APS cavity. Contact pressure is applied by TiG welding outside. Right: Q value and frequency of a cell versus contact pressure.

Another example is the power loss at a contact formed by the brazing technique. Figure 8 shows a pillbox test cavity for studying brazing characteristics. The Q values were measured in TM_{010} mode where the surface RF current flows across the brazing joint. Before brazing, the Q values for several samples are scattered from 91

98%. After silver brazing (BAg-8; Ag 72% + Cu 28%) at 810°C, the Q value becomes larger than 97%, indicating a good electrical joint.

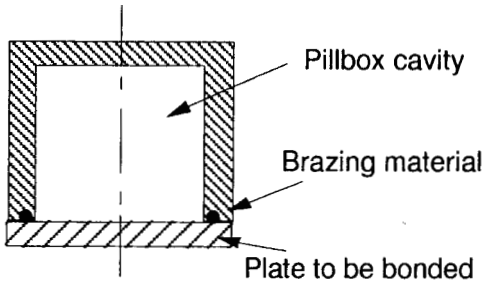


Fig. 8 Brazing test in pillbox configuration. Bottom plate is brazed with a material inserted in wire form.

The last example of obtaining a good contact is the utilization of the diffusion of copper atoms across the junction. This type of bonding naturally requires a very flat surface with good roughness and cleanness without dust, at a high temperature. Starting with ultra-high precision machining of the parts, vacuum-tight bonding with reasonably small deformation of the parts has been achieved above 800°C with resulting good RF contact.

6.5.2 Surface quality

Surface quality is reflected in P_{wall}. In the test shown in Figure 8, two kinds of brazing materials were tested. Each was put intentionally at the center on the bottom plate so that the brazing material would spread over the plate. The Q value for the case with silver brazing material, BAg-8, shows no degradation, but that with the gold brazing material (BAu-11V; Au 50% + Cu 50%) shows considerable degradation, down to 85%. This is due to the low conductivity of the gold-copper alloy[12].

From the author's experience, Q values in realistic cavities run about 95%, even though the test results above show almost 100%. Based on this rule-of-thumb value, rough checking of various qualities such as surface properties, contact condition, and so on can be done to a practical extent.

6.6 Cell alignment

In a structure such as DS, which accelerates a very low-emittance beam, the cell alignment along the structure is one of the most rigid requirements. In order to establish a precision of a few μm, as in Table 2, the diffusion-bonding method of

joining parts becomes essential. This type of bonding is preferable to avoid misalignment due to slippage during a liquid phase in brazing or due to non-uniform stress in a welding process. Figure 9 shows the misalignment of 150 cells along a 1.3m structure. The cells were bonded through diffusion mechanism at 890°C. This result indicates the feasibility of the alignment within several μm over one-meter scale.

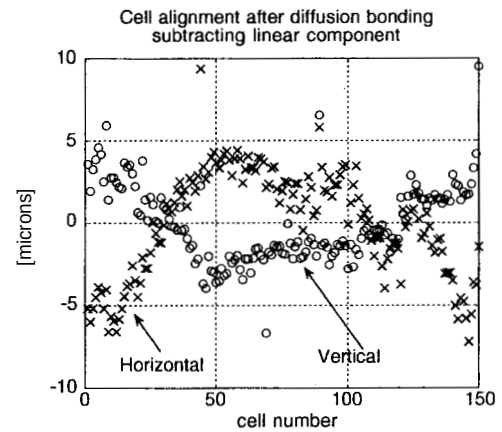


Fig. 9 Misalignment of cells along 1.3m structure after diffusion bonding.

7 Conditioning

It is usually observed that a cavity cannot accept its specified power from the beginning, immediately after fabrication. High input power applied from the beginning might cause severe breakdowns in ceramic windows and discharges at various parts in the cavity. These may result in damage that cannot be repaired. Therefore, the cavity should be gradually trained, starting from a low input-power level, which is usually lower than the specification by more than three orders of magnitude. This process is called "conditioning."

The conditioning is understood to diminish various protrusions or dust on the cavity surface through moderate discharges. However, if the conditioning is too fast, the discharge grows greatly and causes severe damage to the cavity surface. Examples can be seen in the scanning microscope view after an extremely severe breakdown test [13]. In order to prevent the cavity from sustaining such severe damage during power input, there is monitoring of phenomena such as vacuum jump, large RF

reflection from the cavity, and any arc in the wave guide in order to stop power input as soon as any of those phenomena occurs.

Figure 10 shows two examples of conditioning curves, one for 500-MHz CW operation in a SW APS cavity, and the other for X-band pulsed operation in two 20-cm-long constant-impedance TW structures.

The left figure shows two typical conditioning patterns observed in the conditioning of 52 APS cavities for TRISTAN[1]. All 52 cavities were fabricated by essentially the same procedures but some were baked at 150°C for two days before conditioning (curve U33) and others were not (curve U28). The only difference is that the baking replaces the low-power conditioning process. All 52 cavities follow essentially one of these two curves. The arrows mark the power levels at which the increase in input power was slowed because of frequent vacuum increase, sometimes accompanied by discharges. Each of these levels seems to correspond to conditioning of a particular place in the cavity, especially the coupler and the small gaps in coupling cells. This is a typical example of the observation that the same design and the same fabrication methods result in similar conditioning curves.

The right side of Fig. 10 shows the conditioning of two 20-cm-long constant-impedance TW structures[14]. The electrical design of the two cavities is the same, but the one indicated by KEK was made by a fabrication process typical of commercial products for medical/industrial linacs, and the one indicated by CERN

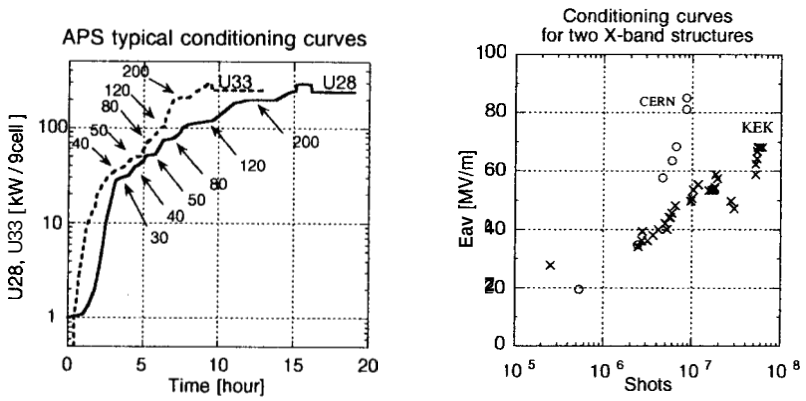
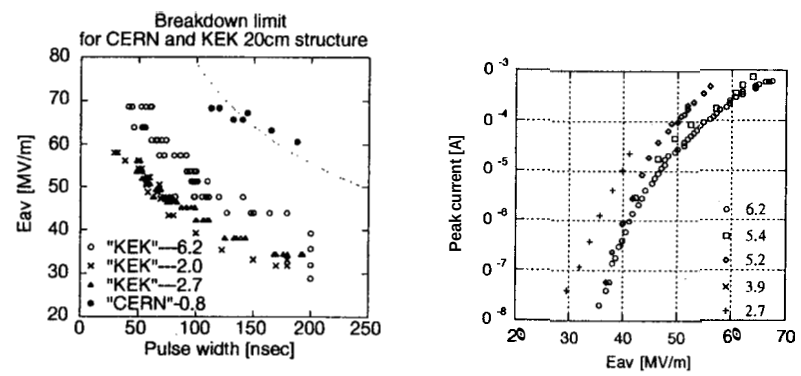


Fig. 10 LEFT: Typical conditioning curves of APS input power versus conditioning time. Those of U28 and U33 are typical examples of no baking and baking before conditioning, respectively. RIGHT: Typical conditioning curves of two X-band 20-cm-long structures. Average accelerating field along the structure is plotted as function of number of RF pulses.

was made at CERN in a study of the structure for a linear collider project, CLIC[15]. The cells for the former were cut by an ordinary lathe; those of the latter by an ultra-precision lathe with a diamond tool. The assembly and tuning of the former was done in a usual clean room but with insertion of a metallic rod that touches the beam-hole irises during tuning; that of the latter was done with cleanness taken into account and tuning performed without touching. The difference between the two structures is clear. The latter reaches 100 MV/m level in a fairly short time, whereas the former cannot reach this level easily with similar conditioning criteria.

As the result of conditioning, the input RF power increases and various characteristics appear: the pulse width in a given field level increases without breakdown; the vacuum level in the cavity improves; and the fault rate, dark current, and X-rays from the cavity all decrease. Figure 11(a) shows the evolution of the conditioning of two 20-cm-long TW structures, which show the gradual increase of the field level and the pulse width of stable operation. Figure 11(b) shows how the dark current from the KEK-made 20-cm X-band structure decreases through conditioning. This indicates the change of the surface quality of the cavity by the conditioning process. The decrease of dark current seems to be reflected in the increase of the breakdown limit, but the relation between these is not yet clear.



(a) (b)

Fig. 11 (a): Breakdown characteristics of a 20-cm X-band structure through conditioning: breakdown points encountered while increasing the pulse length but keeping the same power level. The numbers show the number of pulses from the beginning of conditioning until the measurement. (b): Changes in the amount of dark current by conditioning of the KEK-made 20-cm X-band structure. The numbers are the numbers of RF pulses until the measurement in units of 10^6.

In Fig. 12 are compared the amount of dark current as a function of field for the two X-band structures at the last moment of conditioning: a huge difference is seen. This probably reflects the large difference in the speed of conditioning, shown in Fig. 10. A practical conclusion is that cleanness during fabrication should be of great concern.

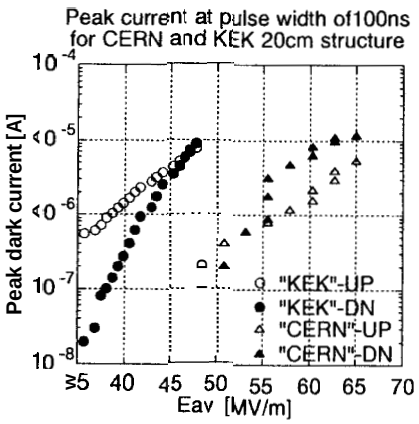


Fig. 12 Comparison of the dark current of the two X-band 20-cm-long structures at the last moment of conditioning as a function of the accelerating field.

How much dark current, and what quality in phase space and in time, are tolerable for the actual application to the accelerator should be discussed. Based on an understanding of the criteria, the fabrication method should then be determined.

8 Summary

Some basic points in designing and fabricating RF accelerating cavities are described by focusing on tuning the frequency and realizing good electrical quality related to Q value. Then, two conditioning examples are presented, and the importance of good quality and cleanness of surface for obtaining stable high field operation is discussed.

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