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TUNING A SUPERCONDUCTING ACCELERATING CAVITY UNDER OPERATING CONDITIONS

PART 2: EXPERIMENTAL

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ABSTRACT

A mechanical support for a superconducting 4-cell accelerating cavity was constructed. It served as a means of tuning to the design frequency, of obtaining field flatness and of measuring the field flatness at 4.2 K.

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1. INTRODUCTION

A superconducting 4-cell cavity has been built and tested [1,2]. The aim of this experiment was to gain experience in the handling and the treatment of large multicell cavities for storage ring applications and to check for unexpected features particular to multicell cavities.

A superconducting cavity operating in a storage ring has to oscillate within about ± 5 kHz of the correct frequency, so it should be equipped with a system for adjusting the frequency at 4.2 K. Such a cavity, constructed from niobium sheet, also needs a mechanical support. In addition, the determination of the accelerating field E_{acc} makes use of the computation of the field configuration for an ideally flat tuned cavity. Thus a device for measuring and adjusting the field flatness at 4.2 K is necessary.

Finally, one peculiarity of superconducting accelerating cavities is that they are not limited by the total dissipated power but by point-like surface imperfections, which either drive the cavity surface normal by a thermal instability or give rise to the emission of electrons, which may increase the total losses of the cavity. Thus the maximum field is determined by the cell which contains the worst surface imperfection. By reducing the field excitation in that particular cell the overall accelerating field might be increased considerably. Thus a device for a controlled detuning of a particular cell is useful.

The mathematical method underlying such a tuning device is described in [3]. This report serves as a continuation and gives the experimental results.

2. THE SUPPORT

The support described here satisfies the above requirements. The idea underlying its construction is the following. The cavity is considered to be represented by a system of coupled single cells with individual frequencies, which are excited in the π-mode. A constant amplitude ("flat" field distribution) is established in all single cells of a multicell cavity if the resonance frequencies of the individual cells and the coupling between neighbouring cells are equal. For this reason the end cells of a 4-cell cavity are smaller in diameter than the standard cell to compensate for the influence of the cut off tubes (fig. 1). Manufacturing tolerances, however, create deviations from the ideal frequencies which must be corrected.

A study with SUPERFISH [4] and LALA [5] has given the following approximation for the frequency change, Δf, of an individual cell of the 4-cell cavity as a function of the cavity dimensions

$$\Delta f\ [\mathrm{kHz}] = 460\ \Delta a\ [\mathrm{mm}] - 2000\ \Delta b\ [\mathrm{mm}] + 140\ \Delta r\ \ [\mathrm{mm}] + 600\ \Delta d\ [\mathrm{mm}]$$

a, b, r_1, r_2 and d are defined in fig. 2. The dependence on r_2 is negligeable.

So, the frequency of an individual cell can be changed by deforming some part of the wall e.g. by changing the cell length.

The mechanical deformation of the 4-cell cavity by external forces has been computed [6]. A change in cell length mainly results from a change in d and should allow for the adjustment of the frequency of an individual cell.

A support was manufactured, by means of which the length of an individual cell may be changed without affecting the other cells (fig. 3). It consists of five plates fixing the 4-cell cavity at the irises. This provides mechanical rigidity. The top plate is fixed to the cryostat and each lower one is attached to the next plate above. The distance between two neighbouring plates is maintained by three rods. These rods act as screw jacks to vary the distance between plates. They are equipped with a thread at one end and are turned together by a chain system driven by a shaft passing through the cryostat cover. Turning this shaft by 180° counter clockwise corresponds to an increase of cell length of 1 mm. The force on the cavity due to the external pressure is compensated by springs beneath the lowest plate. All measurements were performed with the cavity in a vertical position and for the accelerating mode (π mode) only.

3. TUNING

Tuning to field flatness(*) and frequency is performed by an iterative procedure. It consists of measuring and adjusting steps. It is based on the analysis of a coupled oscillator model, which represents a multicell accelerator structure and is discussed in [3].

The first step of the experimental procedure has to determine the field excitation of each individual cell. A given deformation of one cell will change the resonant frequency of the structure by an amount Δf which is proportional to the electromagnetic energy stored in that cell and therefore proportional to the square of the accelerating field in this particular cell. From the Δf values obtained by a fixed deformation of each cell of the structure one finds the field excitation of the real structure. This is used according to the prescription given in [3] to compute the frequency deviations of the single cells from the ideal frequency. The deformations of each cell, which correspond to these frequency deviations, are known experimentally. Thus by applying these deformations on the single cells each of them can be tuned to the correct value. After this procedure has given a flat field distribution, the whole structure may be tuned to the design frequency by applying a constant deformation on each cell. In practice, the last step was combined with the preceding ones.

The measuring process consists of increasing each cell length by $\Delta \ell = 1/6$ mm, reading the corresponding change in resonance frequency, Δf, and restoring the cell to its original length. The same procedure is performed for a decrease in cell length of the same amount. The two measured Δf are equal with a precision of ± 0.6 kHz. The average Δf is calculated. This technique is repeated for each cell and results in

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(*) Throughout this report the field flatness is defined to be the ratio of the stored energies of the two cells with the minimum and maximum excitation. By well known theorems the stored energy in a particular cell is related to the resonance frequency change Δf of the cavity induced by a perturbation of the field configuration of that particular cell.

four Δf (see table 2). The backlash of the system is eliminated by turning the driving rod in one direction only. Required changes in cell lengths, $\Delta \ell$, [6] to compensate for the deviation of the resonance frequency of the 4-cell cavity from its design value and give a flat cell excitation are computed from these Δf by a program based on a lumped circuit model. This program was run on a small laboratory computer (HP 9845B).

After performing the recommended change, $\Delta \ell$, the field flatness is measured again. The field flatness is established to 90% (which corresponds to 2.3% r.m.s. deviation from the average accelerating field) or better (see table 2). With about two measuring and adjusting steps a field flatness of 95% can be obtained eventually.

4. EXPERIMENTAL RESULTS

The main features of the tuning support were measured (table 1). ϕ is the turning angle of an individual driving rod which corresponds to a length change $\Delta \ell$ of the corresponding cell. All measurements of field flatness were performed within the linear range $-30° < \phi < 30°$ (fig. 4) which gave the best reproducibility. $\Delta \ell$ can be adjusted with a precision of ± 7 µm. The maximum $\Delta \ell$ applied was 3 mm. We never observed a degradation of the cavity Q after a tuning experiment.

The experimental result $\Delta f/\Delta \ell$ = 86 kHz/mm may be compared with the result from the computer study. This yields $\Delta f/\Delta d$ = 600 kHz/mm for a one-cell cavity of the same geometry which is equivalent to 150 kHz/mm for a four-cell cavity.

As $2\Delta d \approx \Delta \ell$ [6] (fig. 2) and $\Delta f/\Delta d \approx 2\Delta f/\Delta \ell$ the calculated result of $\Delta f/\Delta \ell$ = 75 kHz/mm is in reasonable agreement with the experimental result.

The influence of the cooldown and the warming up of the cavity on the field flatness and frequency was studied. The results are summarized in table 2.

The field flatness is influenced by thermally cycling the cavity. It is reduced from .90 to .62 (experiment 1) by cooling from room temperature to 77 K with liquid N_2 in the cryostat, and from .92 to .6 (experiment 2) by cooling from 77 K with liquid N_2 in the cryostat to 4.2 K with He. However, warming up from 4.2 K to room temperature only reduces it from .92 to .81 (experiment 4). This suggests that boyancy forces from the liquid N_2 play a role. This is indeed confirmed by experiments 5 and 6, where the removal of the liquid N_2 (experiment 6) is observed to have the opposite effect on the individual Δf to that seen when cooling down from room temperature to 77 K with the liquid in the cryostat (experiment 5). Experiment 7, which showed the flatness unchanged when cooling from 77 K to 4.2 K in gas, gives another confirmation. A complete thermal cycle (warming up and cooling down again) does not influence the field flatness (experiment 8).

In experiment 3 it could be demonstrated that one particular cell (which showed a higher electron loading) can be detuned as required. The overall accelerating field E_{acc} in the cavity could be increased by 10% without increasing the losses due to electron loading. The field flatness was reestablished within an error of ± 3% when the detuning was removed.

The following frequency changes due to cooldown were measured:

- 300 K → 77 K (with liquid)	400 kHz
- 77 K (with liquid) → 4.2 K (with liquid)	120 kHz
- 77 K (with liquid) → 77 K (no liquid)	61 kHz
- 300 K → 4.2 K (with liquid)	520 kHz
- 77 K (no liquid) → 4.2 K (with liquid)	53 kHz
- 4.2 K → 300 K → 4.2 K	6 kHz

5. CONCLUSION

The tuning process of superconducting a 4-cell accelerating cavity was successfully performed. The tuning support allows the tuning of the frequency and field flatness and the measurement of the field flatness at 4.2 K. In addition it gives mechanical rigidity to the cavity. The tuning is accomplished by iterative measuring and adjustment steps with the help of a computer program. A field flatness of 0.95 is attainable. The flatness is only modified by 10% by cooling down the cavity from 300 K to 4.2 K.

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TABLE 1

Main Features of the Tuning Support for the 4-cell cavity

Range used for tuning	$-30° < \phi < 30°$
Δf ($\phi = \pm 30°$)	± 14.3 kHz
Reproducibility for Δf	± 0.6 kHz
Reproducibility for $\Delta\ell$	± 7 µm
$\Delta f/\Delta\ell$	86 kHz/mm
Backlash	10°
Attainable field flatness	95% ± 1%

Δf is the resonance frequency change of the 4-cell cavity due to a length change $\Delta\ell$ of an individual cell. A cell length increase $\Delta\ell = 1$ mm corresponds to a counter clockwise rotation of the driving rod by $\phi = 180°$. The field flatness is defined to be the ratio of minimum stored energy per cell to the maximum one.

TABLE 2

Tuning Experiments

No.	T[K]	Δf [kHz], (field flatness)				f[kHz] π-mode	Change in f(kHz) π-mode
		Cell 1	2	3	4		
1	300 77 (with L.N$_2$)	12 (.93) 10 (.62)	12 (.92) 12 (.79)	13 (1.) 16 (1.)	11 (.90) 14 (.92)	498491 498902	+ 411
2	77 (with L.N$_2$) 4.2	15 (.95) 16 (1.)	14 (.92) 10 (.60)	16 (1.) 12 (.74)	15 (.97) 12 (.75)	498888 499008	+ 120
3	Detuning cell 4 4.2 Back	15 (1.) 17 (1.) 15 (1.)	15 (.99) 15 (.91) 14 (.96)	15 (1.) 16 (.94) 15 (1.)	14 (.94) 10 (.61) 13 (.88)	499014 499008	- 6
4	4.2 300	15 (.94) 15 (.92)	15 (.92) 14 (.81)	16 (1.0) 15 (.98)	15 (.92) 13 (1.)	499110 498566	- 544
5	300 77 (with L.N$_2$)	14 (.88) 12 (.67)	13 (.85) 14 (.81)	14 (.92) 17 (.94)	15 (1.) 18 (1.)	498566 498956	+ 390
6	77 (with L.N$_2$) 77 (without L.N$_2$)	15 (.93) 17 (1.)	15 (.94) 14 (.84)	15 (.94) 13 (.74)	16 (1.) 13 (.76)	498944 499005	+ 61
7	77 (without L.N$_2$) 4.2	14 (.97) 14 (.97)	14 (.98) 14 (1.)	15 (1.) 14 (.99)	14 (.99) 14 (.98)	499003 499056	+ 53
8	4.2 → 300 → 4.2	14 (.96)	14 (.96)	14 (.95)	14 (1.)	499062	+ 6

Δf = change of resonance frequency of the π-mode due to a length change of a particular cell $\Delta\ell$ = 1/6 mm

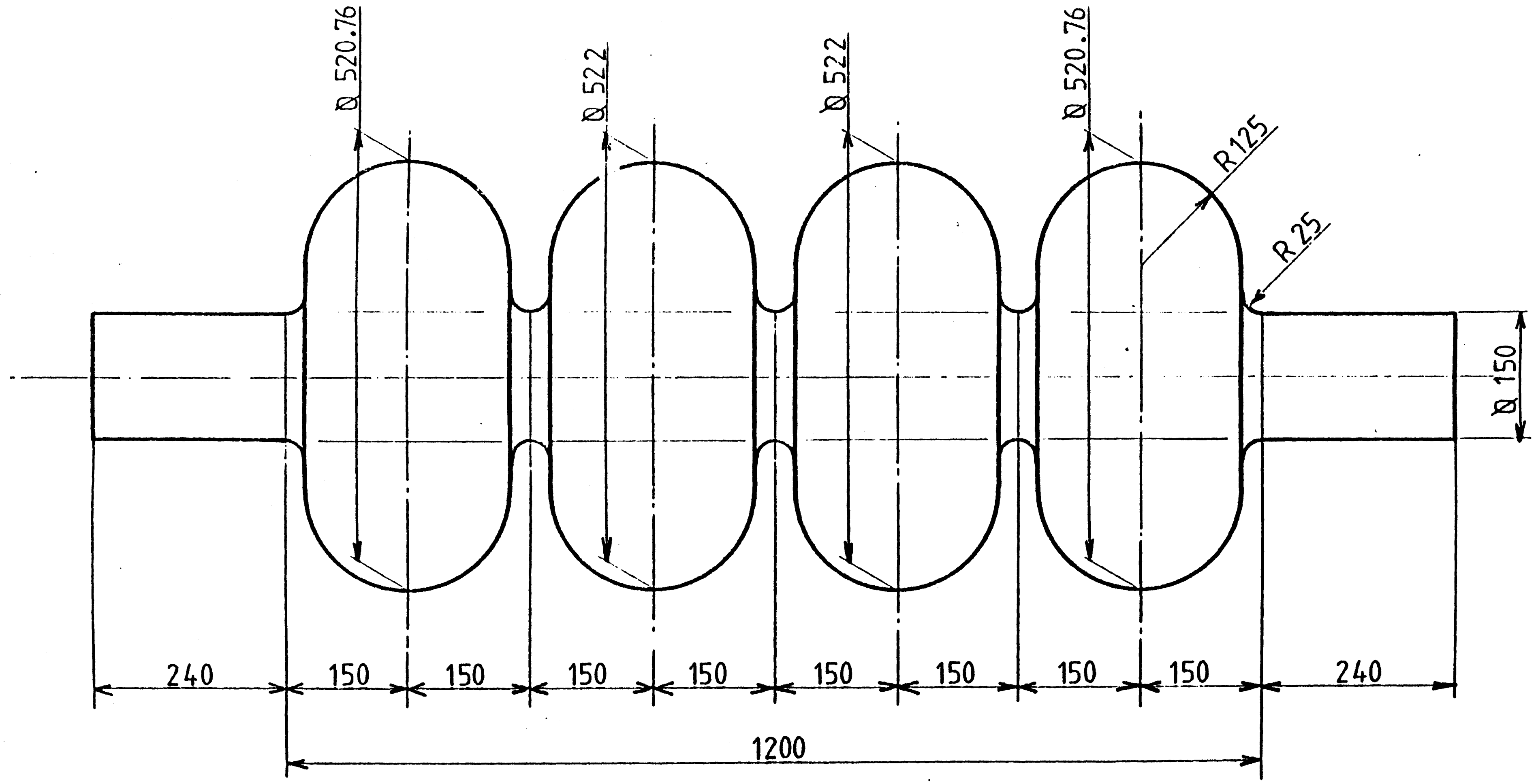
FIGURE CAPTIONS

Fig. 1 Main dimensions of the 4-cell cavity.

Fig. 2 Definition of a, b, d, r_1, r_2.

Fig. 3 The tuning and support system.

Fig. 4 Resonance frequency change Δf as a function of cell length deformation $\Delta \ell$ measured in degrees of the turning angle of the driving shaft.


Ø 520.76
Ø 522
Ø 522
Ø 520.76
R125
R 25
Ø 150
240
150
150
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150
150
150
240
1200

Fig. 1

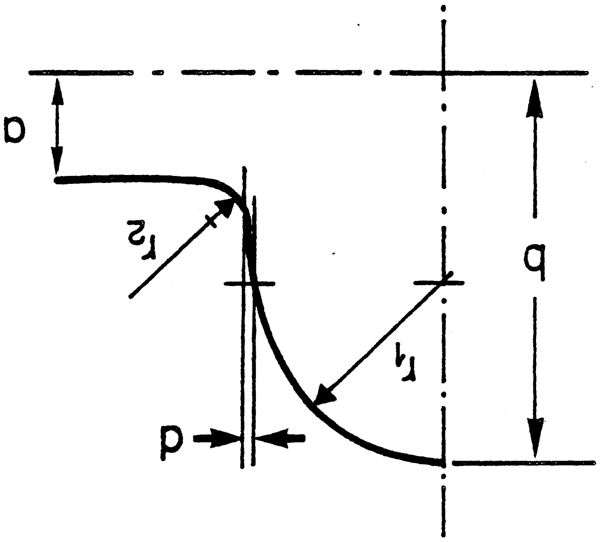
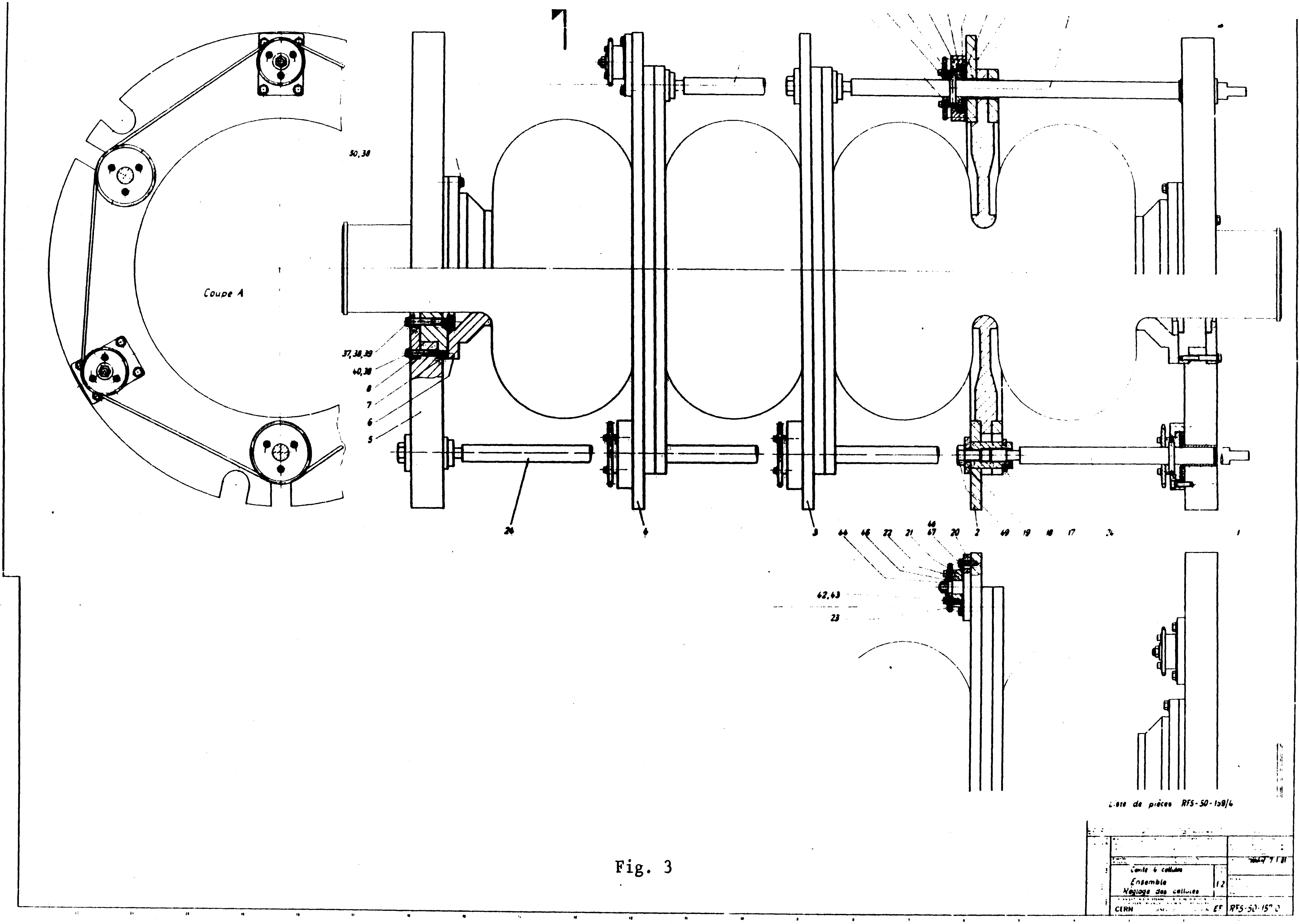


Fig. 2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Coupe A
37,38,39
40,38
8
7
6
5
24
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3
44
45
22
21
46
67
20
2
49
19
18
17
24
1
42,43
23
Liste de pièces RFS-50-159/4
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Ensemble
Réglage des cellules
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CERN
EF
RFS-50-157 0
7 1 81

Fig. 3

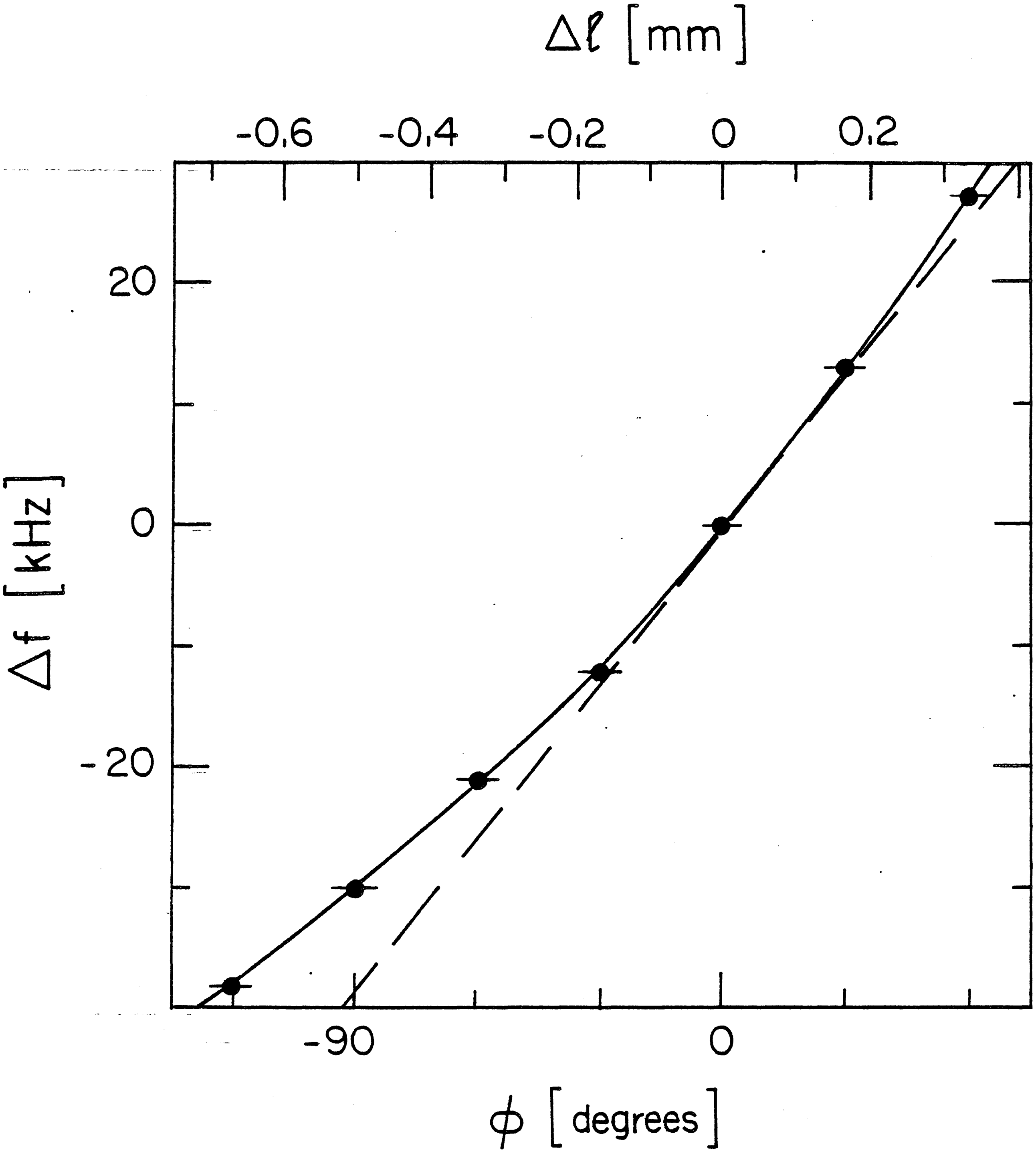

Fig. 4