CHARACTERIZATION OF LD-CUT RESONATORS OPERATING IN ANHARMONIC MODES

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ABSTRACT

As shown in [1], resonators operating on the first anharmonic modes (n01 or n10) can be driven by means of two pairs of cross connected electrodes. The width of the gap between the electrodes and its orientation are the main parameters that enable to obtain a better electrical response on the metrological mode, or more exactly, a worst response on the B-mode. The consequence can be the removal of the selective circuit usually inserted in any oscillator using a SC-cut resonator. In this case, we hope for increasing the short term stability.

In the same way, it is possible to decrease the phase fluctuations in using a doubly rotated quartz resonator with a very low isochronism defect as described in [2].

So the use of two pairs of electrodes on the new LD-cut resonator (LD for Low isochronism Defect) seems very interesting for time-frequency field applications.

In this paper, we compare firstly the theoretical results showing the influence of these two pairs of electrodes on SC and LD-cut resonators. Secondly, we present some experimental results concerning the variation of the motional resistances of the two thickness-shear vibrating modes versus the gap width and the directions of the applied field.

INTRODUCTION

As shown previously, the amplitude frequency effect may have a significant influence on the short term stability of oscillators because of the phase noise caused by the amplitude noise [3]. These last years, we have found a new cut with a quasi-null ID (Isochronism Defect). Furthermore, the C-mode of this called "LD-cut" is temperature compensated and so can be used for time-frequency field applications.

Furthermore, we proved that it is possible to keep good electrical parameters of the temperature compensated mode and to deteriorate the B-mode by using two pairs of crossed electrodes. Their geometries are calculated for the shape of the considered mode.

So, the goal of this publication is to present the experimental characteristics of the LD-cut (LD is for Low Isochronism defect) and their comparisons with the properties of the well-known SC-cut.

Before presenting these results, we wish to recall here that the resonant frequencies of each vibrating modes (A, B and C) are calculated from the constants of dispersion [4] M'_n and P'_n (n being the overtone number) which depend, of course, of the mode family. As the motional resistance of a given mode, it is dependant of the constants α_n and β_n governing the mode shape. This is explained with more details in [3].

In the next table (Table I), in addition to the constants of dispersion, we present also the angle of the orientation of the modal figure ψ'_n. It is important to note that the higher is the difference between ψ'_n for B-mode and ψ'_n for C-mode, the higher is the discrepancy between their motional resistances. In other words, it is possible to determine α (see figure below) to obtain the best ratio between the motional resistances of the B- and C-modes.

Table I : Dispersion constants (in 10^9 N/m^2) and orientation angles of each mode-shape :
1. Theoretical values

LD-cut	Overt.	M'_n	P'_n	ψ'_n
C-mode	3	40.07	60.81	-7.9
	5	64.65	76.02	**-2.7**
B-mode	3	64.72	2.74	-30.5
	5	48.46	68.29	**37.51**

SC-cut	Overt.	M'_n	P'_n	ψ'_n
C-mode	3	53.14	63.29	21
	5	71.02	78.16	28.5
B-mode	3	67.49	28.35	32
	5	51.27	71.62	-37.5

2. Experimental values for the 3rd Ov. of LD-cut

LD-cut	Overt.	M'_3	P'_3	ψ'_3
C-mode	3	45.7	67.8	**# -3**
B-mode	3	66.5	21.9	**# -25**

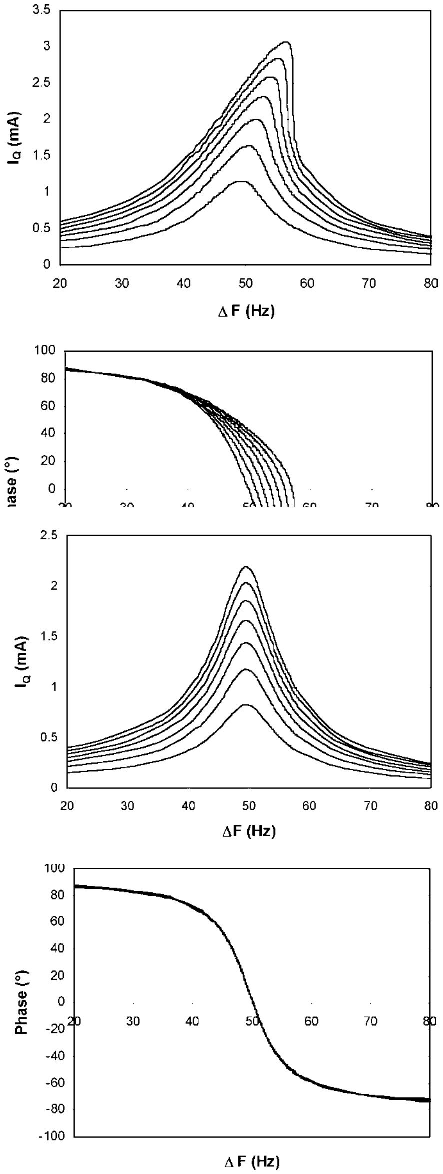
CHARACTERIZATION OF THE LD-CUT

The following figure presents the difference on the Isochronism Defects of the C-modes third overtone of the SC- and LD-cut.

Usually, the SC-cut is defined by the couple of angles φ = 22° and θ = 34° (in IRE 49 standards) whereas the φ angle of the doubly rotated LD-cut is close to 27°, with no high change in θ.

Fig. 1: Isochronism defect for SC- and LD-cuts (respectively top and bottom) when the power increases from 100 to 700 µW (amplitude and phase)

The geometrical characteristics of our resonators



are chosen to optimize the third overtone (C300), defined at 10 MHz. So, their compared theoretical parameters are presented on the table II.

Table II: Electrical parameters of the C-modes 3rd Ov. of the SC- and LD-cuts

	R (Ω)	L (H)	C (fF)	C_0 (pF)	Q ($.10^6$)
LD-cut	135	2.85	0.09	2	1.3
SC-cut	85	1.76	0.14	2	1.3

The frequency temperature curves of these cuts are compared below (Fig. 2), their coefficients being given in the table III.

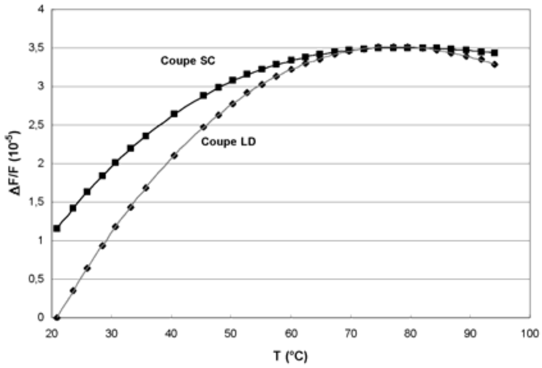


Fig. 2 : Frequency temperature curves

Table III: Coefficients of the frequency versus-temperature for the previous C-modes

	a (10^{-6}°C^{-1})	b (10^{-9}°C^{-2})	c (10^{-12}°C^{-3})
LD-cut	1.23	-14.6	36
SC-cut	0.89	-12.8	56

Table IV : Resonant frequencies of symmetric and anti-symmetric modes : SC- and LD-cuts

	SC-cut (Rc = 230 mm)		**LD-cut (Rc = 300 mm)**	
	f_r (KHz)	**Rm (Ω)**	**f_r (KHz)**	**Rm (Ω)**
C300	10,000	85	10,000	135
C310	**10,065**		**10,051**	
C301	**10,071**		**10,060**	
C320	10,128	130	10,107	265
C302	10,140	140	10,122	275
C321			**10,161**	
C312			**10,171**	
C340	10,258		10,211	
C322	10,267		10,228	
C304	10,282		10,245	
B300	10,914	55	10,755	60
B301	**10,975**		**10,785**	
B310	**10,998**		**10,817**	
B302			10,821	
B320			10,877	

At least, the table IV shows the comparisons between the frequency spectra of the SC- and the LD-cuts in the 10 to 11 MHz range. We give also the values of the radii of curvature Rc determined from the constants of dispersion in the aim of well trapped the energy of vibration in the center of the resonator.

The measurements have been performed under vacuum with electrodes deposited on “condensers” of BVA-type resonators. To drive symmetric and anti-symmetric modes, we connect electrodes to apply different directions of the electric field as indicated in the following figure (Fig. 3).

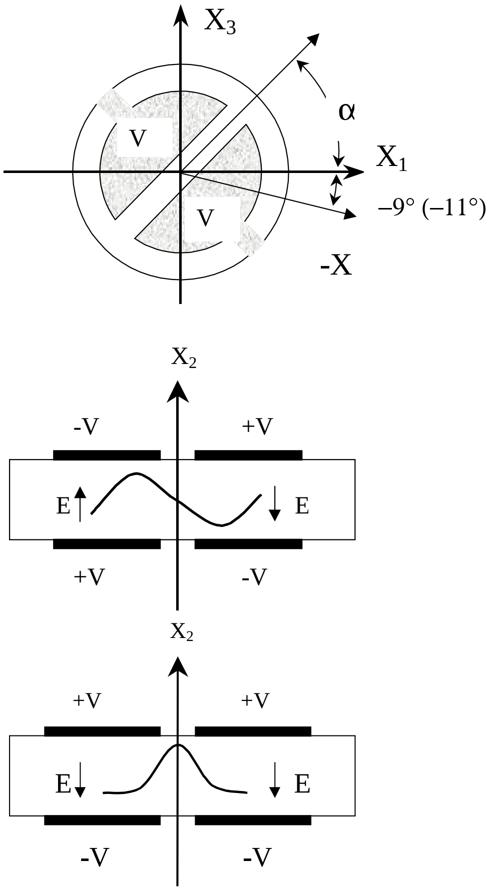


Fig. 3 : Connections to drive anti-symmetric and symmetric modes

X-RAY TOPOGRAPHIES

The X-ray topographies, presented below in the Figure 4, are performed on an electroded BVA type resonator for which the active part (or central part) is separated from the dormant part by four bridges orientated in directions minimizing the force-frequency effect. As predicted by the calculation of the dispersion constants and the orientation of the mode shape, they show, first that the 3rd overtone of the B-mode and its anharmonic modes are more trapped than the C-modes and second that the modal figures are aligned in the calculated direction. However, as we will see below, the difference between the motional resistances of the modes belonging to the same overtone is not so high.

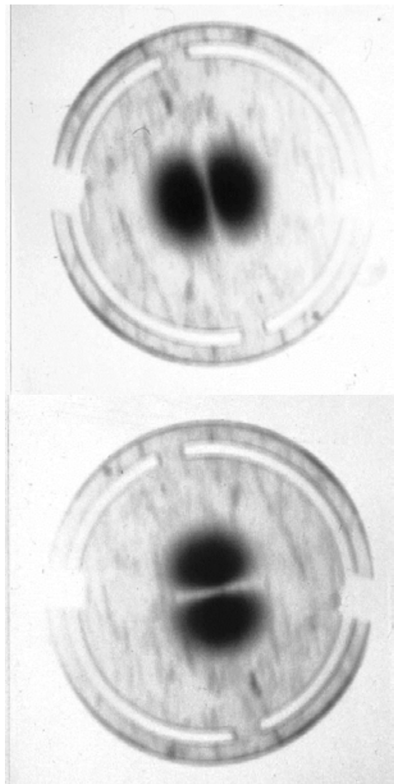


Fig. 4a: Two first anti-symmetric modes (310 and 301) of the LD-cut 10 MHz 3rd Ov. of the C-mode

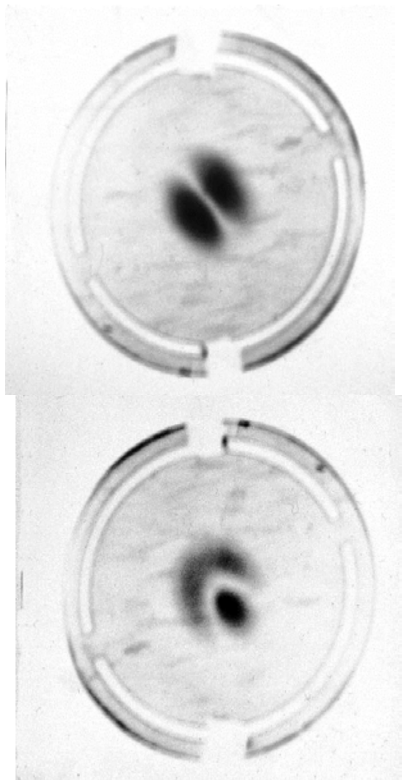


Fig. 4b: Two first anti-symmetric modes (301 and 310) of the LD-cut 10.75MHz 3rd Ov. of the B-mode

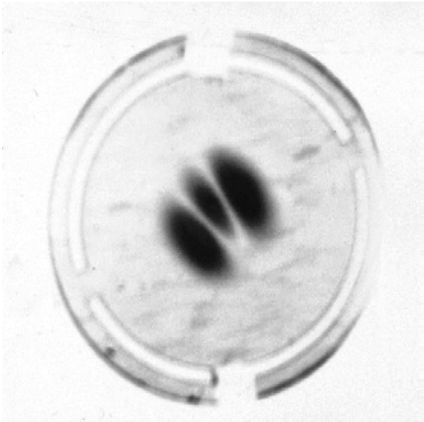


Fig. 5: B302 mode located at 10,821 KHz (close to B310 at 10,817 KHz)

Here, we present also the B302-mode which is very close to the B-310 (see Table IV) and so both perturbated.

EXPERIMENTAL RESULTS

Below, we present experiments realized on LD- and SC-cut resonators with electrodes for which the diameter was fixed to 6 mm and the gap between the half-electrodes at 1 and 1.2 mm. The measurements have been performed under atmospheric pressure so that the values are 2.5 times higher than under vacuum.

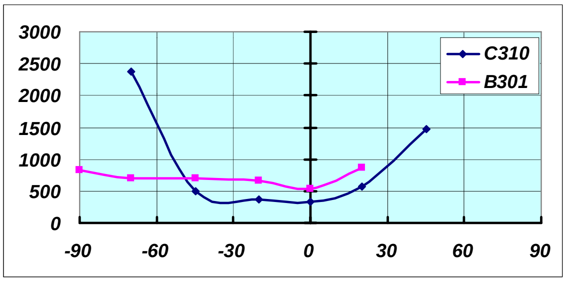


Fig. 6: Motional resistances for anti-symmetric modes (3rd Ov.) of the LD-cut with gap = 1.0 mm

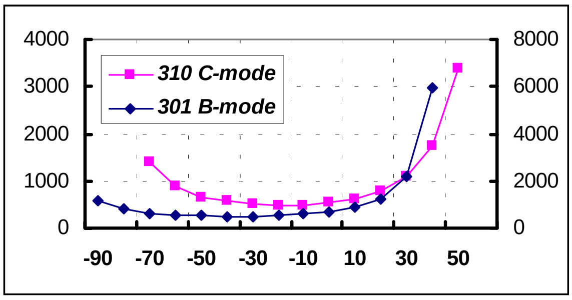


Fig. 7: Theoretical values for LD-cut (gap=1.2 mm)

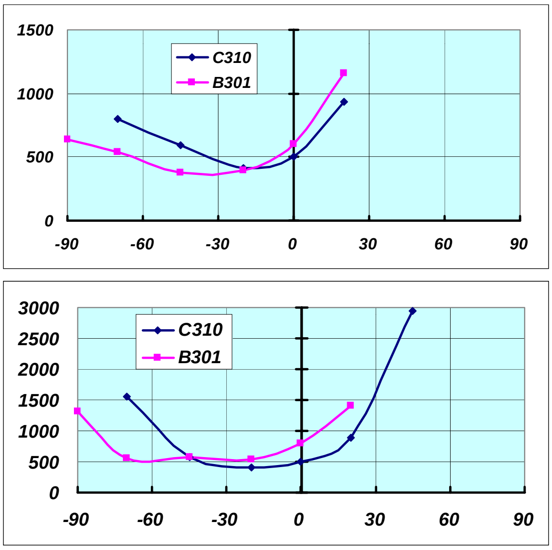


Fig. 8a, 8b: Experimental values of motional resistances obtained for SC- (8a) and LD-cut (8b) with gap = 1.2 mm

CONCLUSION

This first results are obtained with electrodes not really optimized. Though we are fairly agree with the theoretical values, the X-ray topographies show that we have to modify the design of the electrodes to provide a better compromise between optimization of C-mode resistance and increase of B-mode one.

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