Personal Notes on Record Specifications:

The IEC & DIN groove specifications for 30cm LP are often quoted as under. These figures are *arbitrary mixture* from different standards/times and inconsistent or dubious as I remark in parentheses (italics).

- IEC Inmost Recorded Groove Radius 60.325mm=2 3/8inches *(The metric number was expressed as diameter 120mm in IEC98-1958. Moreover its application for commercial record is questionable since it is defined originally for transcription records only.)*
- IEC Outmost Recorded Groove Radius 146.05mm=5 3/4 inches *according to IEC98 1st edition 1958, but IEC adopted metric figure 146.3mm since 1964:* ***In BS1928-1965 previous diameter 11.5inches is amended to read 11.52inches according to IEC95-1964*** See Comparative Table of Standards for 30cm LP.
- DIN Inmost Recorded Groove Radius 57.50mm (*mentioned in DIN 45547: June 1981*)
- DIN Outmost Recorded Groove Radius 146.05mm (*146.3mm as per DIN 45537-1962 & DIN 45547-1981. In DIN I could not find the source for 146.05 which seems simple metric conversion from 5 3/4 inches as quoted in IEC98-1958.* ***I feel that generally before 1960 IEC followed BS/US record industry standards and since 1960 IEC followed DIN industry standards esp. their measuring methods.***)

Recently I read IEC60098(1987-still valid) as under:
Clause 8.4 Lead-in groove. The pitch of lead-in groove shall be 1.2 plus-minus 0.4mm.
Clause 8.5 Outer diameter of recorded surface. diameter 292.6 for 3033&3045(30cmLP33/45rpm) 241.8 for 2533 and 168.3 for 1733/1745 respectively.
Clause 8.8 Lead-out groove. The pitch of lead-out groove shall be 6.4 plus-minus 3.2mm. The lead-out groove shall have at least one turn.
Clause 8.9 Finishing groove. The diameter shall be 106.4 plus-minus 0.8mm for 3033/2533/3045 and 97.4 plus-minus 1.0mm for 1733/1745
Clause 11.2 Tripping mechanism. When the pickup is in the playing position, the tripping mechanism of a record player shall not become operative at a diameter of more than 127mm. *This is also corresponding to clause 8.7 Marker space between bands: marker spaces shall not be located inner than diameter 127mm.*

Original documents are available from IEC in Switzerland

History of IEC 98:
First Edition-1958: Recommendations for lateral-cut commercial and transcription disk recordings. *This original edition was using inch as unit!* because "These Recommendations are based on proposals prepared by the British National Committee of the I.E.C., acting as Experts' Group No.2 of Technical Committee No.29, Electro-acoustics". It was noticeable that Union of Soviet Socialist Republics and Brazil as well as USA, European countries and UK jointly voted explicitly in favour of publication. These proposals were first discussed in September 1954. Hence only lateral-cut/monaural record was a subject for discussion at that time. The document contained two separate sections: commercial records (E) and professional (transcription) records (F).
Second Edition-1964: Processed Disk Records and Reproduction Equipment. Stereophonic fine groove records and channel orientation were introduced while transcription disk recordings were excluded from this edition. **In 1972 IEC98A was issued as First Supplement to Publication 98(1964) with subtitle: Methods of measuring the characteristics of disk record playing units.** My Note: Some of the measuring methods presented in 98A were approved as world standards while some methods (for example: tracking ability=minimum tracking force for a test record with the average recorded levels) were found immature and abandoned later. It seems that every issue contains a temporary opinion or method which is destined to be modified or deleted.
Third and Final Edition-1987 (current coding 60098): Analogue audio disk records and reproducing equipment. Fine groove monaural and stereophonic records are specified while coarse groove SP is excluded.

JIS S8502-1973 (Disc Records) stated:
JIS Inner Recorded Groove Radius: more than 57.6 (diameter 115.2mm)
JIS Outer Recorded Groove Radius: less than 146.5 (diameter 293mm)
JIS Finishing Groove Radius: 53.2mm (same as IEC&DIN)/Lead-out pitch: 4mm~9mm (similar to IEC)
JIS S8502-1973 contained following explanation (3.7(2)): "Outer diameters and various groove diameters are decided after researching the automatic players' actuating dimensions. Diameters for the end of music groove were not specified in IEC. One may think that this can be decided from finishing groove and lead-out groove. In 1966 JIS specified the diameters for the end of music groove in order to handle the record players equipped with **auto-stop function**." JIS Standard S8502 for Disc Record was first established in 1956 and have been revised in 1958, 1959, 1962(including stereophonic groove and groove guard), 1966(considering automatic players and deleting 78rpm record), 1969(revival of groove guard for 17cm 45rpm), 1973 and 1976. It was replaced by S8601-1981 (Disk records) which was abolished in 1994 at last.

NAB's inmost groove: 2.25inches=57.15mm? as per Audio Magazine 1980/Jan. I think NAB's 57.15mm was applicable for the records produced in USA for the decade of monaural LP records, i.e. from 1948 to early 50s until RIAA setting to normalize equalization curve. I heard that recommendation by RIAA was made in June 1953 to produce records based on RIAA equalization from 1954 onward. NAB[1964] indicated the diameter of innermost modulated groove shall not be less than 4 3/4inch for LP and not less than 4 1/4inch for EP (these are same as RIAA as per Bulletin No. E 4 around 1964). The writer of Audio Magazine misquoted NAB standards or quoted older NAB standard without specifying published year and the range of application (transcription or commercial record etc). **Standards are apt to be changed by time and circumstance and also by group or party involved. Moreover the end (or replacement date) of a standard is usually neglected by us while one can remember the start of a standard. Very often one can assume specific practice or convention as a standard, but such is actually never confirmed nor accepted outside of a specific party or group.**

Anyway I think the above figures are maximum or extreme (recordable) and not average values of the produced records.

First I search DIN office in net and find corresponding DIN standards there. Next I search amazon.co.jp and find the brochure DIN-Handbook 523 with title: **PHONOTECHNIK** (ISBN 3-410-12616-3) containing DIN standards (1966-87) and German translation from IEC98-1987 (analogue record) and IEC908-1987 (CD format). **Now IEC98-1987(current coding 60098) is standard worldwide** (BS7063-1989 is also equivalent English part) and to be revised around 2007 if vinyl format continues to be produced in sufficient scale – maybe impossible to my regret.

In the meantime I revisited library at JIS building (Japanese Standards Association) to find IEC98-1958 and BS1928-1965. Accordingly I made a table among standards: click and see Comparative Table of Standards for 30cm LP. Actually in the first edition of IEC98 (Section F5 Page 21) **4 3/4inches (120mm)** as the "minimum diameter of recorded surface" was quoted for **transcription recordings (for broadcasting use) only**. There is no corresponding description about inner diameter for commercial disk records (in Section E). I think exact conversion to 120.65mm from 4 3/4inches (instead of 120mm) has no specific meaning since every division on a scale is simply following to the specified unit: but a fool might question about the excellence in definition between inches and metric units! Fact is: "Figures in inch unit precede those in mm for IEC98-1958 & BS1928-1965" since inch instead of international metric unit was (is still?) widely used in UK/USA etc.

Mr. Keith Howard in September 2003 for a British audio magazine (Hi-Fi News), is quoting current IEC figures (first time in this kind of geometry article as far as I know) in his article named <Squaring up to arm geometry>. I appreciate his neutral approach which is free from almost dogmatically fixed set of null points:66/120.9mm. He is proposing sample set of null points:63.6/119.5 based on inmost radius 58mm and outmost radius 146mm. Incidentally this sample linear offset length 91.55mm is near to 91.535mm for SME Series 300 arms (1989) which might be based on Stevenson Type 1A for 12inches LP proper since SP/EP were no more main formats for music.

General Dimensions of Disks	Standard Play (SP) 30cm	Extended Play (EP) 17.5cm	MP 25cm	LP 30cm(12inch)	Transcription 16inch Disks as specified in IEC98-1958
Type of groove	COARSE GROOVE	FINE (MICRO) GROOVE			MIXED GROOVES: FINE or COARSE
Innermost **radius (mm)** of music groove	47.6 RIAA(circa1963)	53.975 RIAA(1963)/53 JIS(1966)	57.6 JIS(1966)	57.5 DIN(1981)/57.6 JIS(1966)/60.325 RIAA(1963)	60 for fine groove 33.3rpm*see remark, 47.5 for coarse groove 78rpn for coarse groove 33.3rpm

Outermost **radius (mm)** of music groove	146.3 IEC98(1964&1987)/146.05 RIAA(1963)&IEC98(1958)	84.15mm or 3.3125inch IEC&RIAA/84 JIS(1966)	120.65 IEC(1958)/120.9 IEC(1964)/121 JIS(1966)	146.3 IEC(1964&1987)/146.5 JIS(1966)/146.05 RIAA(1963)&IEC98(1958)	196.85
Remark*: In the first edition of IEC98 (Section F5 Page 21) the "minimum diameter of recorded surface" 120mm (4 3/4inches) is quoted for transcription recordings (for broadcasting only. There is no corresponding description about minimum diameter for commercial disk records (Section E). However RIAA indicated 4 3/4inches(120.65mm) as minimum diamete music groove for commercial LP records. **In original standards only diameters have been quoted conventionally.** Sometimes in actual records we find irregular disks which are not complying with any standard. *These minimum diameters are determined historically for every format. I think the main factors are minimum groove speed and the applied tip radius of reproducing stylus. Minimum groove speed [=rpm*minimum recorded groove diameter*PI()/60] in my rough estimation: 20cm/s or 21cm/s for LP, 25cm/s for EP, 39cm/s for SP, 33cm/s for transcription coarse gr 33.3rpm. EP can sound better than LP when the same stylus is used.*					

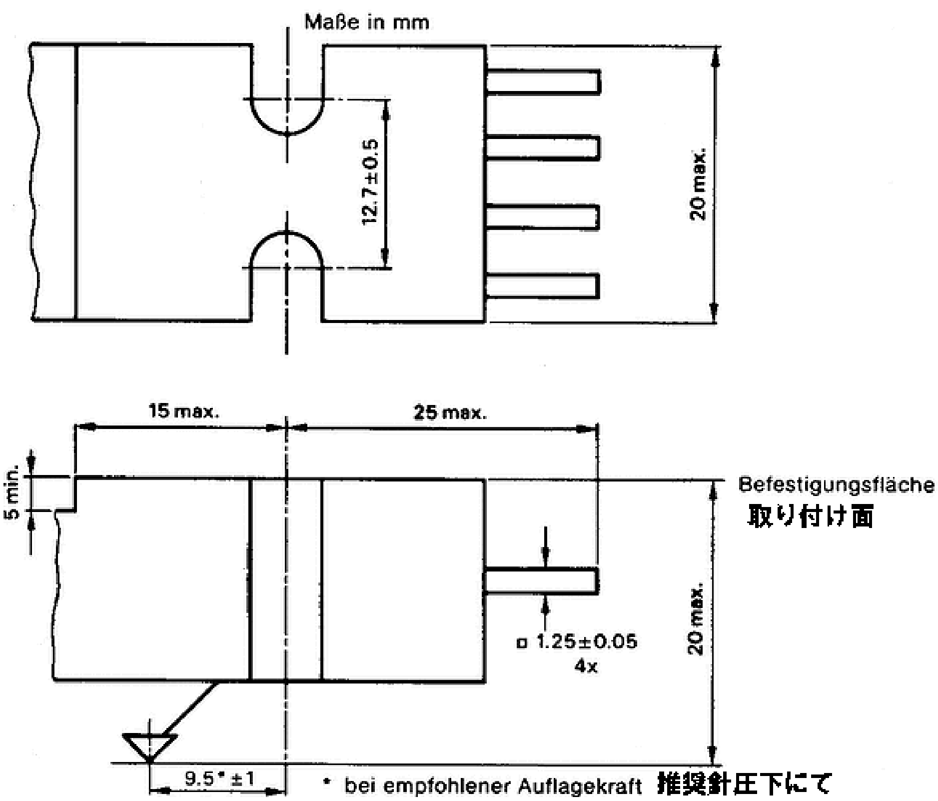
I note down interesting points (to me at least) from DIN-Handbook 523 as follows:

IEC60098: Analoge Schallplatten und -Abspielgeräte; Identisch mit IEC 60098:1987(Analogue audio disk records and reproducing equipment: same as IEC 60098:1987)

I was in doubt about my rapid reading of IEC60098 (original in French/English) and perused this German translation in 1989. I make following notes about the inner/outer groove radius.

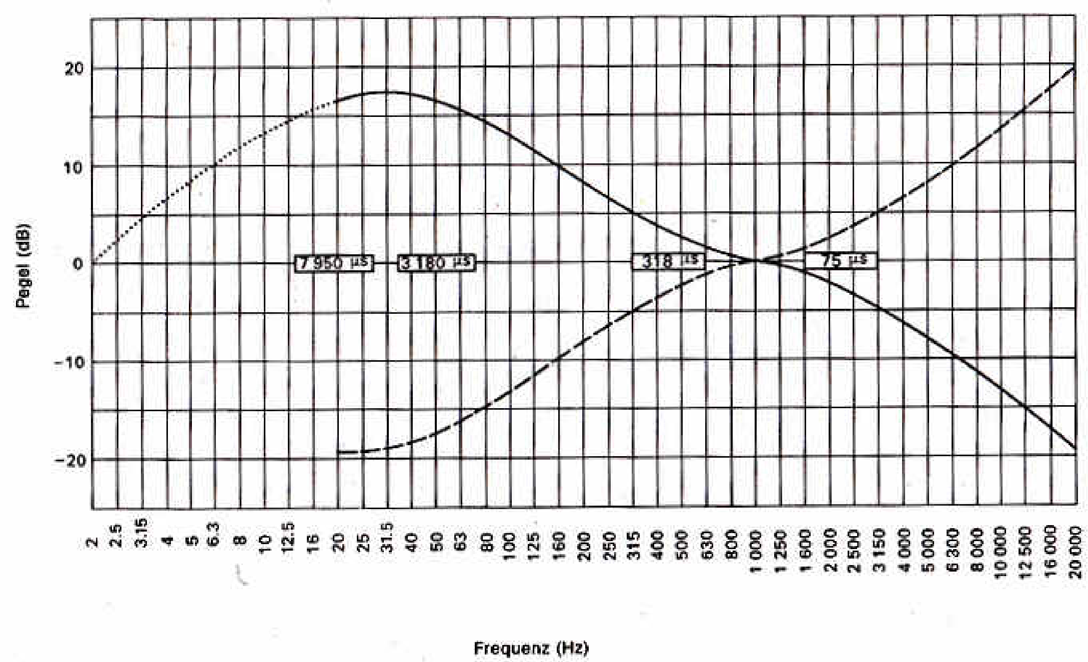
- From clause 8.5: The outer recorded groove radius shall be **less than <u>146.3mm</u>.**
- From clause 8.8/8.9: The inmost recorded groove radius for 30cm LP can be interpreted in various ways. *No specific value, but I assume more than 59.6mm as intermediate value between <u>56-63.2mm</u> where finishing groove radius (53.2mm±0.4mm) + one turn of lead-out groove pitch (6.4mm±3.2mm) = inmost recorded groove radius. Then minimum 57.5mm in DIN is covered by extreme minimum 56mm in this IEC because DIN/IEC adopted same specifications about finishing groove radius and lead out pitch.*

I find an interesting article about distance from the centre of mounting holes of cartridge to stylus tip. Fig.2 in connection to clause 11.5 shows **9.5mm±1mm** at recommended tracking force. This clause 11.5 recommends: mounting screw M2.5 (or M2.6 where M2.5 is not available) and cartridge weight (mass) not exceeding 12g. *I think the odd number 9.5mm as distance is derived from 3/8inches as often Shure cartridges have such value. In JIS C5503(1979) about Phonograph pick-ups, the value is indicated as 10mm±3mm (wide enough for almost all cartridges to fall in this range). There is no special reason to adopt inch instead of mm since IEC would adopt international metric unit generally. It is only a matter of conventional practice and depends on the products available or most popular at the time.*



Clause 8.1 Direction of groove modulation: suitable vertical tracking angle (VTA) is 20degree +5/-0. The resulting modulation shall be <u>optimum</u> for reproducing styli having a rake angle (SRA) of between 0 and -5degrees.
I think effective vertical modulation angle (VMA) recorded in vinyl should match vertical tracking angle (VTA) for cartridge. Recommended VTA (and VMA) in 60's was about 15degrees and then in 70's it became 20degree +/-5 and from early 80's it became 20degree +5/-0. VMA is not equal to cutter head angle on lacquer. The cutter head should be more inclined than effective modulation angle due to the elasticity of lacquer. IEC98-1964 & BS1928-1965 have a following NOTE: "In practice, angles of between 0degree and 25degrees may be encountered" . VTA of cartridges in early '60 was ranging between 8degrees (Neumann DST1212) and 36degrees(Shure M77) -see <u>VTA</u> of old cartridges.

In comparison with RIAA(3180/318/75µs, 50/500/2120Hz), this IEC (clause 10.2.1) suggests an additional time constant 7950µs/20Hz in order to suppress subsonic noise. **It results in 3dB difference at 20Hz between recording and reproduction as under. Clause 10.2.2 Tolerance for reproduction chain: a) 2-20Hz reproducing curve should be on or under the dotted line b)20Hz-20kHz no tolerance is stipulated.** In practice some preamplifiers are equipped with subsonic filter 12dB/Oct under 15Hz for the same effect since IEC time constant (and its curve 6dB/Oct) is an example. *IMO: Historically speaking the bass limit for phono amplifier is changing by time. Before 1950 low limit was often not stipulated since there was natural bass limit in microphone/amplifier/speaker. Later in Hi-Fi era after developing LP, the handling frequency for microphone/amplifier/speaker has been much extended and there arises a need for suppressing rumble noise (and low frequency resonance between arm mass and cartridge compliance which has became lower than 20Hz). "Nominal" low limit: year 1948 Columbia LP 100Hz>1954 RIAA 50Hz>1987 IEC additional 20Hz.*



Frequenz Hz	Pegel dB	
	Aufnahme	Wiedergabe
2	–	– 0,1
2,5	–	+ 1,8
3,15	–	+ 3,7
4	–	+ 5,7
5	–	+ 7,6
6,3	–	+ 9,4
8	–	+11,2
10	–	+12,7
12,5	–	+14,1
16	–	+15,4
20	–19,3	+16,3
25	–19,0	+16,8
31,5	–18,5	+17,0
40	–17,8	+16,8
50	–16,9	+16,3
63	–15,9	+15,4
80	–14,5	+14,2
100	–13,1	+12,9
125	–11,6	+11,5
160	– 9,8	+ 9,7
200	– 8,2	+ 8,2
250	– 6,7	+ 6,7
315	– 5,2	+ 5,2
400	– 3,8	+ 3,8
500	– 2,6	+ 2,6
630	– 1,6	+ 1,6
800	– 0,8	+ 0,8
1 000	0	0
1 250	+ 0,7	– 0,7
1 600	+ 1,6	– 1,6
2 000	+ 2,6	– 2,6
2 500	+ 3,7	– 3,7
3 150	+ 5,0	– 5,0
4 000	+ 6,6	– 6,6
5 000	+ 8,2	– 8,2
6 300	+10,0	–10,0
8 000	+11,9	–11,9
10 000	+13,7	–13,7
12 500	+15,6	–15,6
16 000	+17,7	–17,7
20 000	+19,6	–19,6

IEC 60098(IEC98-1987) is modifying or replacing DIN 45538(definitions of terms), 45539(guidelines for measuring method, specifications, connection, exchangeable pickup system, requirement on reproducing amplifier etc), 45546(StereoRecord 45rpm), 45547(StereoRecord 33rpm) and 45548(criteria for record reproducing equipment). The following are extracts mainly from DIN standards.

DIN 45500 T3 (1975):Heimstudio-Technik (Hi-Fi); Minderstanforderungen an Schallplatten-Abspielgeräte (Hi-Fi technics; requirements for disk record reproducing requirements)

This standard is almost similar to IEC 60581-3(1978) defining minimum performance requirements. Both standards mentioning: allowable deviation from rated speed +1.5%-1%/wow and flutter ±0.2% maximum/Rumble ratio more than 35dB unweighted and 55dB weighted (in addition to rumble IEC specified reference signal-to-hum ratio more than 50dB at reference velocity 3.83cm/s rms and reference frequency 315Hz)/static VTF maximum 0.03N/channel unbalance less than 2dB at 1kHz/channel separation over 15dB between 500Hz (315Hz in IEC) and 6300Hz: over 20dB at 1kHz/VTA 20±5degrees. This standard comments on compliance (static measured) for every direction to be minimum 0.8cm/N (8x10^[-6]cm/dyne) corresponding to the maximum braking force (resilience=Rückstellkraft) 7.5mN (0.75p) measured at displacement 60μm. The compliance for lateral direction shall be bigger than that for vertical direction. Further mentioning: rated output voltage of velocity sensitive pick-ups (for example magnetic cartridges) to be 5 to 15mV at 1kHz with load 47kΩ for peak velocity 10cm/s (channel sensitivity 0.7 to 2mV/cm/s as per IEC). In case of displacement=amplitude sensitive pick-ups such as piezoelectric cartridges: 0.5 to 1.5V with load 470kΩ for peak velocity 10cm/s. FIM (frequency intermodulation) distortion at tracing -6dB reference tone shall be lower than 1%. Standard spherical stylus tip radius 15+3-0μm and standard bi-radial tip radius 6μm and 18μm.

This IEC specified separation of R from L and L from R respectively and made note: Separation and crosstalk are equivalent only if there is no unbalance output between R/L. In IEC98-1987: Separation precedes crosstalk because separation is independent of channel sensitivity. Hence playing back test record with R or L signal alternatively, the separation of channel L from channel R: 20log(L output voltage from L channel signal divided by L leakage voltage from R channel signal), the separation of channel R channel from channel L: 20log(R output voltage from R channel signal divided by R leakage voltage from L channel signal). And indicate smaller value of measured channel separations at 1kHz.

Allowable deviation from rated speed +1.5%-1% is too large. Provided the speed deviation +/-0.2% is allowed, the drift of strobe-patterns shall be as following table. To get exact 45rpm at 50Hz, patterns should be drifting -15/minute. See also my EXCEL file for rpm & strobe pattern designs. IEC98-1987: Besides using conventional strobe disc (method A), 120 revolutions of a record are timed by means of a stop watch (method B) for *T* 160seconds for 45rpm or *T* 216 seconds for 33 1/3rpm defining the mean deviation as *(T-t)/t* x 100% where *t* shall mean the measured time passed during 120 revolutions. Measuring method B is accurate because it is independent of the power supply frequency deviations for strobe light. Hence in some turntables equipped with quartz-locked signal generators, the generated signals are used for motor control and strobe light.

My note about the sensitivity of cartridge: The velocity of groove modulation is usually expressed as peak cm/s while output voltage is conventionally shown as mVrms in accordance with the indication of millivoltmeter. Relative output in this DIN (5 to 15mVrms for peak velocity 10cm/s) is equivalent to sensitivity in IEC expression (channel sensitivity 0.7 to 2mV/cm/s where output mV and velocity cm/s are both either effective [rms] or peak values). DIN45500 &45539 about cartridge output were often misused and outputs were expressed incorrectly as "mV/cm/s or mVs/cm" while original DIN indicated relative output in mVrms for peak recorded velocity. IEC 60581-3 was based on DIN, but maybe IEC people became aware of such misuse in practice so that they made remark: "output mV and velocity cm/s are both either effective [rms] or peak values" when expressing output in mV/cm/s. I will never know this fact unless I notice the difference of specific output numbers as described in DIN and IEC. See also the English part of "frequency record" (output test of 4 monaural cartridges). **In German text, peak velocity is marked with symbol v^ while effective velocity is marked with v^{eff}. Accordingly all the velocities (cm/s) quoted hereunder shall mean peak values if not specified.**

50Hz Power Supply (Mains)			60Hz Power Supply (Mains)		
RPM	number of stripes or dots on strobe disc	drift number per minute	RPM	number of stripes or dots on strobe disc	drift number per minute
77.92	77	-6 to +18	78.26	92	-38 to -10
45.11	133	-27 to -3	45.00	160	+/-14
33 1/3	180	+/-12	33 1/3	216	+/-14

According to JIS C5521-1975 (phonomotor test method): 100/3 revolutions at groove radius 12cm and 45 revolutions at groove radius 8cm are measured with the usual stylus pressure on each plain groove. *IMO: Because of stylus pressure (& drag force) influencing on turntable, rpm would be increasing a bit toward inner groove in most turntables other than Direct Drive turntables. Diameter of the conventional Strobe Disc (around 10cm) was made similar to the label size for checking rpm with record putting on turntable. We forget this reason and feel happy to have bigger strobe disc and measure rpm without loading of stylus pressure upon record.*

DIN 45538 (1969):Begriffe für Schallplatten-Abspielgeräte (Definitions for disk record reproducing equipment)

This standard defined terms such as relative deviation from nominal RPM/Wow and flutter/Margin for rumble/pick-up system/cartridge/stylus/tracking force/resilience (Rückstellkraft)/compliance/channel separation/VTA/reproduced frequency/effective stylus mass etc. 'Rückstellkraft' is defined as a force which must be overcome by stress force so that stylus tip can be moved from set position. **Tracking force/Resilience/Compliance can be measured at null frequency (static) or at specific frequency (dynamic)**. *IMO: The term 'Rückstellkraft' is identical to stiffness as 1/compliance for example 2g/100micron=980*2dyne/0.01cm=196000dyne/cm stiffness which can be converted into static compliance about 5.1*10^(-6)cm/dyne.*

DIN 45541 (1971):Frequenz-Mess-Schallplatten (Frequency test record St 33 and M33, Stereo and Mono)

St 33(Stereo:side A) contains Sweep from 31.5Hz to 20,000Hz(L/R), 16 spots Signals for same range. M33(Mono:side B) contains sweep from 31.5Hz to 20,000Hz, 16 spots signals for same range and sweep from 5 to 125Hz (flutter range). 8cm/s for stereophonic recording, 10cm/s for monophonic recording were selected each as reference recorded velocity 0dB in 70's. **See also DIN 45543** which amended velocity 0dB for monaural recording: from conventional 10cm/s to correct 11.3cm/s as calculated.

DIN 45542 (1969):Verzerrungs-Messschallplatte (Distortion test record St 33 and St 45, Stereo)

Side:A St33: recorded vertically=hill and dale modulation **Tiefenschrift**, this side for the measurement of VTA is recorded at various vertical modulation angles from 6 to 30 degrees with complex (Doppel) tones of 1850Hz+3150Hz & 370Hz+630Hz for measuring vertical tracking angle of a cartridge. Velocity of each frequency component is fixed at 3.8 cm/s. When the output of total tone 5000Hz or 1000Hz is measured lowest, the ring shall indicate corresponding vertical tracking angle of a cartridge. **Vertical tracking angle measured with total tone 1000Hz shall be declared in data sheet.**

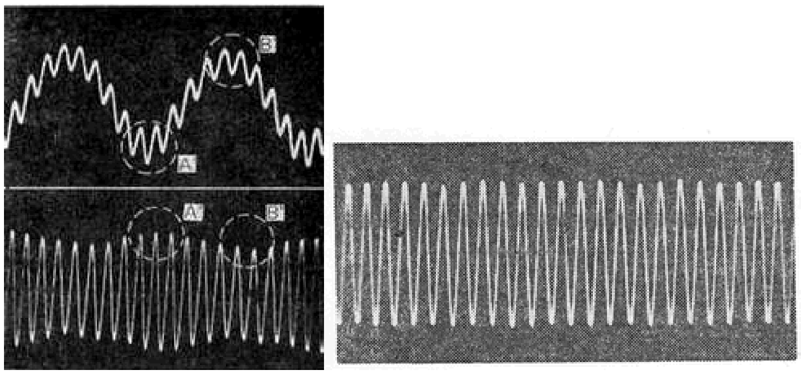
Side:B St45/33: recorded on flank(45 degrees)=**Flankenschrift** (vertical modulation angle fixed at 15degree) 300Hz+3000Hz for 33rpm or nearly 400Hz+4000Hz for 45rpm for the test of nonlinear distortions with stereo pick-ups. 0dB: f1=300Hz with velocity 8cm/s, f2=3000Hz with velocity 2cm/s, i.e. velocity rate is 4:1 for 300Hz/3000Hz (11cm/s:2.8cm/s for nearly 400Hz/4000Hz). Playing with 33.3rpm, frequency intermodulation distortion (**FIM**) can be measured by determining the degree of frequency modulation of f2 by f1. Ortofon often declares these data for their cartridges as *FIM distortion at recommended tracking force, DIN 45542: < 1% etc.* Wow-flutter/Drift meter in accordance with DIN 45507 can be applied with this frequency pair (300Hz+3000Hz). Instead of weighting filter, switch on RC HPF with time constant 1ms (=around 160Hz) enabling to suppress frequency modulation (FM) caused by wow-flutter of turntable. Playing with 45rpm, intermodulation distortions (**IMD**) in accordance with DIN 45403 can be measured. Search-tone-analyser (FFT?) is recommended since demodulation method (amplitude demodulation) may indicate false value of distortion arising at tracing (Phase modulation). Geometric distortion due to stylus tip shape is compensated upon recording except for two rings - cartridge with stylus tip radius 15µm and vertical tracking angle 15degree shall be used as standard for this test record (see my note 1). **The rate of nonlinear distortions arising at -6dB reference tone shall be declared in data sheet.** See also DIN 45549 about FIM. *My Personal Notes: 1)By 1969 TELDEC (US Patent 3457374 etc) developed tracing simulator for compensating expected geometric distortion due to the spherical stylus tip tracing on groove. But then the respective designed curvature of spherical stylus tip must be used? About such question JVC engineers explained in a Japanese book (1979) that "in any case tracing distortion is reduced as if smaller tip radius is used because |r-r0|<r (r: applied stylus tip radius, r0: designed value of stylus curvature for tracing compensator)" see a drawing introduced in my Japanese page about tracing simulators & recording compensators. 2)FIM & IMD. I am wondering how two different measuring methods in accordance with speeds are possible while the nature of recorded signals is essentially same? There have been various terms and different approaches to modulation distortion measurement: CCIF IMD/SMPTE IMD/DIM (dynamic intermodulation distortion) /Thiele IMD (total difference frequency distortion) and so on!!!*

Side A: Vertical Tracking Angle Test with complex (Doppel) tone in vertical modulation						
Band	Vertical Modulation Angles	f1 (Hz)	f2 (Hz)	velocity for f1 (v1)=velocity for f2 (v2) (cm/s)	recorded time (second)	Sum tone f1+
A1	6/10/14/18/22/26/30 degrees (total 7 rings)	1850	3150	3.8	each 10	5000
A2	6/10/14/18/22/26/30 degrees (total 7 rings)	**370**	**630**	**3.8**	**each 10**	**1000**

Side B: Non-linear Distortions Test at 45degrees components					
Band	Ring number within band	Channel	Relative level (dB)	recorded time St33 (second)	Remarks
B1	1/2/3/4/5/6/7	L	-12/-10/-8/-6/-4/-2/0	each 12	
B2	1/2/3/4/5/6/7	R	-12/-10/-8/-6/-4/-2/0	each 12	
B3		**L**	**-6**	**35**	**Representative Level for I measurement**

B4		**R**	**-6**	**35**	**Representative Level for I measurement**
B5	1/2/3/4/5/6/**7**	L	-12/-10/-8/-6/-4/-2/**-6**	each 12	Geometric tracing distortion compensated upon recordin ring **No.7**.
B6	1/2/3/4/5/6/**7**	R	-12/-10/-8/-6/-4/-2/**-6**	each 12	
St45: rotation at 45rpm for side B		*f1=400Hz**	*velocity 11 cm/s*	*0dB*	
		*f2=4000Hz**	*velocity 2.8 cm/s*		
St33: rotation at 100/3rpm for side B		*f1=300Hz**	*velocity 8 cm/s*	*0dB*	
		*f2=3000Hz**	*velocity 2 cm/s*		
Remark on rotations and frequencies: Recorded frequency is shown 1% lower at 100/3rpm and 1% higher at 45rpm because 45:100/3 is not exactly 4:3.* My note: Exact ratio 45rpm divided by 100, =1.35, hence above four velocities for 0dB seem to be rounded approximately while frequency ratio of f1:f2 retains exact vale 1:10 and velocity ratio 4:1.					

I picked up the following pictures from Yamamoto (1971). Left upside: Reproduced wave by cartridge of VTA 16 degrees tracing on test tone of 400Hz+4000Hz recorded with VMA 2.5 degrees. Left downside: Wave of 4000Hz component. Right: 4000Hz component reproduced with VTA 16 degrees cartridge on test tone 400Hz+4000Hz recorded with VMA 15degrees. The difference 13.5 degrees between VMA & VTA might be an extreme case. But it is not impossible if we consider VMA variation of stereophonic records from 15 to 23 degrees & VTA variation of actual cartridges deviating +/- 5 degrees from nominal value. [8+5=13]



DIN 45543 (1984):Meßschallplatte zur Messung des Frequenzganges und der Kanaltrennung (Frequency response and separation test record)

This record combines frequency test (sweep 20 to 20,000Hz Lateral), channel separation test (spot 20 to 20,000Hz Alternating L/R), and arm resonance test (3 to 500Hz Lateral and Vertical): thus replacing older test record DIN45541(Stereo and Mono) technically. This test record made in accordance with DIN45547-1981(Stereophonic disk record 33 1/3rpm) should have bottom groove radius smaller than 4micron and VMA 23degrees for stereophonic recordings. *A test record based on this standard was produced by DGG.*

Band	Kind of Recording	Effective value cm/s	Peak value cm/s	REMARKS
Side A: signals are recorded with DIN/IEC/RIAA characteristic/time constants 3180-318-75microseconds.				
A1	Lateral	8	11.3	Reference Tone Level = 0dB 1kHz 15seconds
A2	Vertical	8	11.3	Reference Tone Level = 0dB 1kHz 15seconds
A3	Left Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
A4	Right Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
A5	Left channel	-10dB level of band A3: sweep from 20Hz to 1kHz and -20dB sweep from 1kHz to 20kHz		
A6	Right channel	-10dB level of band A4: sweep from 20Hz to 1kHz and -20dB sweep from 1kHz to 20kHz		
A7	L/R alternative	-20dB 1kHz		
A8-A18	L/R alternative	-20dB spot 20kHz/18kHz/16kHz/14kHz/12.5kHz/10kHz/8kHz/6.3kHz/4kHz/2kHz/1kHz		
A19-A27	L/R alternative	-10dB spot 1000Hz/500Hz/250Hz/125Hz/80Hz/63Hz/40Hz/31.5Hz/20Hz		
A28	L/R alternative	-10dB 1kHz		
Side B: signals are recorded with time constants 3180-318microseconds (excluding top lift 75microsecond).				
B1	Left channel	-10dB level of band B5: sweep 20Hz to 20kHz		
B2	Right channel	-10dB level of band B6: sweep 20Hz to 20kHz		
B3	Lateral	-10dB level of band B7: sweep 20Hz to 20kHz		
B4	Vertical	-10dB level of band B8: sweep 20Hz to 20kHz		
B5	Left channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
B6	Right channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
B7	Lateral	8	11.3	Reference Tone Level = 0dB 1kHz 15seconds
B8	Vertical	8	11.3	Reference Tone Level = 0dB 1kHz 15seconds
B9	Lateral	-22dB level of band B7 : sweep 3Hz to 500Hz		
B10	Vertical	-22dB level of band B8 : sweep 3Hz to 500Hz		

By the way 1) how about the relation between 0dB & recorded velocity?
According to Vinyl Lexikon by Frank Wonneburg published in year 2000: <*following to RIAA/IEC 8cm/s for stereophonic records, 10cm/s for monophonic records and 12cm/s for MaxiSingle*>.

DIN 45537(1962)Monaural Records:*peak 10cm/s at 1000Hz with the reservation that its value is to be approved internationally.* Later 10cm/s for monaural 1kHz test tone is replaced by 11.3cm/s. Often readers & writers misunderstand the true intention of documents and overlook the time when these documents were made (funny enough standards for vinyl records are made a few years after the appearance of new products).
DIN 45547(1981)Stereophonic Records: *effective 5.6cm/s* (=peak 8cm/s) *at 1000Hz*
Any velocity level was optional/stopgap because to get same output level from stereo & monaural grooves *with stereo cartridge*: stereo one channel recorded velocity towards 45degrees = monaural velocity/√2. Hence 8x√2=11.3cm/s for monaural recording is indicated in the above table from DIN 45543. Of course these are again optional and another pair (Stereo channel-wise 3.54cm/s 45 degrees and Mono 5cm/s laterally) can be selected as reference 0dB as often applied on cartridge sensitivity test. *Each 0 dB level can be different in every test record according to the purpose of measurement: I prefer the description in velocity (cm/s) than obscure dB. 0dB as recording level index cannot be standardised since the recording level should be determined backward from the conventional capacity of cutting machines and pick-ups.*

2) how to measure recorded velocity?
According to IEC98: the alternating velocity that a rotating disk would impart to the stylus of a pick-up having *low mechanical impedance and negligible dimensions of stylus tip*. Such perfect cartridge is not yet existing! Hence the recorded velocity of a sinusoidal groove modulation may be measured with an optical method (the Buchmann-Meyer light-band method measuring the width of reflected light patterns). G. Buchmann und E. Meyer, Eine neue optische Messmethode fuer Grammophonplatten. Electrische Nachr-Techn. 7(1930). Another method is based on the theoretical/geometrical value of velocity: ***Peak Velocity for sinusoidal modulation = amplitude or displacement of modulation from centre (0 to peak)*2pi*frequency***. For instance 3.14cm/s: 5micron amplitude for 1kHz, 50micron for 100Hz and so on.

VARIOUS TEST RECORDS measuring output voltage or SN ratio or output difference between L/R	DENON XG-7001 & JVC TRS-1007 etc	JIS Monaural Standard Record JIS C-5507 & JIS Stereo Standard Record JIS C-5514*(see bottom explanation) etc	NAB Test Record	DIN Test record		CBS-Lab STR-100
1kHz reference level recorded in test record	Stereo (each channel i.e., L/R alternatively) 3.54cm/sec peak for 45 degrees	Lateral 5cm/sec peak	Lateral 7cm/sec peak	Stereo (each channel) 8cm/sec	Lateral 10cm/sec peak *or 11.3cm/sec (DIN 45543)*	Stereo (each channel i.e., L/R alternatively) 3.54cm/sec **rms** for 45 degrees
level of each one channel (45degrees peak) peak signal velocity conversion for stereophonic pickups	**3.54cm/sec**	**3.54cm/sec**	**5cm/sec**	**8cm/sec**	**7cm/sec *or 8cm/s (DIN 45543)***	**5cm/sec**
Why lateral groove is used in JIS for measuring output voltage of stereo pickups. I think it is because of measuring output difference between L/R at a time. JIS C 5503-1979(Phonograph Pickups) explained clearly "lateral peak 50mm/sec should be converted to 35.4mm/sec peak 45degrees for stereo pickups". Please note the difference in definition between relative output (mVrms for certain velocity *peak or rms*) and absolute sensitivity (mV/velocity in IEC definition) as explained earlier.						

DIN 45544 (1971):Rumpel-Meß-Schallplatte (Rumble measurement test record St 33 and M 33, Stereo and Mono). The measuring method is based on DIN 45539.

Side A: Stereo L flank/R flank & Vertical/Lateral Recordings 315Hz with peak velocity 5.42cm/s and long plain groove with normal recording=dense pitch to test motor rumble.
Side B: Lateral=Monaural Recording 315Hz with peak velocity 0.54cm/s and long plain groove with recording pitch 0.54mm/turn =0.3mm/s to test rumble voltages (weighted and unweighted), acoustic feedback at plinth or the influence of auto-stop depending groove radius.
The rumble voltage ratio=20log10(output at 315Hz peak 5.42cm/sec divided by output at mute groove)
There is a reference to NAB-recommendation in March 1964. It is said that NAB's values (100Hz peak 1.4cm/s laterally recorded monaural) are lower than values measured with this DIN test record: about -4dB for monaural equipment and -7dB for stereo equipment because of velocity difference converted to 1kHz output and the nature of groove modulation (DIN/IEC=Stereo 315Hz while NAB=Monaural 100Hz). Moreover the measured value according to NAB is unweighted only. 315Hz is selected because it is the limit of weighted curve as well as linear section for evaluation. Peak velocity 5.42cm/s is selected because it is comparable with velocity 10cm/s at 1kHz after passing IEC/RIAA equalization (time constants 3180/318 /75microseconds). **But -5.32dB(=5.42/10) as recording difference between 315Hz and 1kHz was not exact! Hence accurate value 5.51cm/s for 315Hz based on recording difference -5.18dB is adopted later in IEC98(1987). IEC 60581-3(1978!) also indicated 3.83cm/s rms (5.42cm/s peak) based on old data from original RIAA etc before computer calculation based on time constants became easy.** The specific recording/reproducing dB point at 300Hz instead of 315Hz had been indicated in early documents and in early 1970s someone estimated dB for 315Hz and this incorrect figure had been used repeatedly without checking. The correct recording/reproducing dB for 315Hz was indicated as 5.2dB (rounded from 5.179) in IEC98(1987). IEC98(1964)&BS-1928(1965) indicated correct curve for 20Hz-20kHz while the recording curve presented in DIN 45537-1962(Monaural LP record) had irregularity for 30Hz-200Hz (30Hz -17.5dB in DIN45537-1962 vs correct value -18.6dB in DIN45547-1981 for stereo LP) whereas time constants for these standards remain unchanged irrespective of mono or stereo application. We find this kind of small deviations in old documents. It was already known in Japan by 1973 that original RIAA dB numbers had irregularity - JIS S 8502-1973 indicated correct dB up to the second decimal.
My note: SN rates are actually differing by the radius of mute band to be tested - hence I think test on various radii of long mute bands is important though this point is often neglected in recent test data. In many cases SN ratio at inner groove is better than SN ratio at outer radius (maybe because the height variance due to warp might be small toward inner radius of record or because the rate of stylus friction on a groove might become small as per groove velocity in contradiction with the usual theory of kinetic friction? [a mystery to me]). Rumble due to mechanical imperfection at turntable together with Hum due to electric induction mainly at pick-up system can be measured as SN as a result. For example: Playback output of certain signal groove measured as 5mV, playback noise of plain groove measured as 10μV, then SN ratio is calculated as 54dB. I think rumble [more properly SN] ratio more than 35dB unweighted and 55dB weighted as demanded in DIN 45500(1975) &IEC 60581-3(1978) is practical enough as minimum performance target: it is in vain to seek extraordinary big numbers since the SN ratio of vinyl records [due to the lacquer material particle size under 50angstrom] is usually under 65dB at 1kHz weighted by hearing curve and under 50dB unweighted. I am astonished to read the technical leaflet attached to Denon test record XG-7001: "This band consists of non-modulated grooves that are provided for the purpose of measuring the signal-to-noise ratio of the sound system...If these grooves were to have been cut using a common cutting head, there would ensue noises such as hum, so a special non-modulated groove cutting head not equipped with any moving components was assembled and used to cut these grooves." I don't know how about the plain grooves in other test records for measuring SN ratio. Anyway ***a deformation-free plain groove is required for SN measurement.***
IMO: I. It is of no use to measure mechanical rumble alone. II. The "rumble" is an obsolete term since any modern turntable don't make audible rumble as in the early times.
Some methods to check mechanical imperfection or strength as ***the deflection of the revolving plate*** *were presented in JIS C5521-1975 (Testing Method for Record Turntables)" as follows:*
Each measurement is tested for turntable excluding record mat (i.e. bare platter). Measure with dial gauge (high sensitive type with measuring pressure requirement less than 30g).
(1) Static height variance: Without rotating a turntable, put 50g weight at the radius 125mm on turntable and then shift the weight to the opposite place (125mm). And check the height variance of turntable at radius 125mm. Weight 50g is selected in consideration of the current VTF less than 10g and safe rate as x 5.
(2) Revolving height variance: With rotating turntable, check the height variance at 10mm inside from the rim of a turntable.
(3) Revolving lateral variance: With rotating turntable, check the lateral variance at the rim of a turntable.
Each Evaluation of (1) & (2) : The deflection of turntable =height variance at testing point (mm) /testing point (mm) on a turntable.
Though these JIS methods can check mechanical imperfection or strength, the method (1) is not suitable for turntable with floating suspension. According to a Japanese test report around 1980 about first-class 11 turntables from the world (various drives: DD/BD/Idler and various suspension and construction), static height variance according to test (1) was maximum 0.04mm, revolving height variance according to test (2) was maximum 0.23mm and lateral variance according to test (3) was maximum 0.21mm. These figures are negligible if compared with mat flatness and record warps. Besides above JIS, in 1978 Thorens supplied a Rumpelmesskoppler (rumble test coupler maybe inspired by Rabinow's USP3653255-1972) to measure mechanical rumble noise arising from spindle (literal "rumble") - as a result generally 6dB to 10dB higher SN comparing to conventional method using test record could be indicated by this method ***(free from the quality of a test record)****.*
Hence I believe that any modern turntable is free from a mechanical rumble and its SN is mainly influenced by the electrical circumstances. SN is changing in accordance with actual arrangements and nominal SN indicates only potential under ideal (not hearing, only measuring) conditions - it is unreal for users who play records under non-ideal conditions (various acoustic feedback upon hearing).

Band	Kind of	Effective	Peak	REMARKS

	Recording	value cm/s	value cm/s	
Special remark*: *current test records for the time being have 10seconds recording of each signal for side A and 3 seconds recording for side B. It should not be produced anew when new test record is arranged to be made.*				
Side A: Rumble Test Record as per DIN 45544				
A1	Left Channel	*3.83*	5.42	315Hz for 15seconds*
A2	Right Channel	*3.83*	5.42	315Hz for 15seconds*
A3	Vertical	*3.83*	5.42	315Hz for 15seconds*
A4	Lateral	*3.83*	5.42	315Hz for 15seconds*
A5	Mute band	-	-	Long plain groove with normal recording=dense pitch for music up to radius 60mm at least.
Side B: Rumble Test Record as per DIN 45544				
B1	Lateral	*0.38*	0.54	315Hz for 15seconds*
B2	Mute band	-	-	Long plain groove with recording pitch 0.54mm/turn (=0.3mm/s for synchronising paper recorder) up to radius 60mm at least.

Record for Rumble Test according to IEC98(1987)

Modulation	Frequency Hz	Effective value cm/s	Peak value cm/s	Time in second
Left Channel	315	*3.90*	5.51	15
Right Channel	315	*3.90*	5.51	15
Vertical	315	*3.90*	5.51	15
Lateral	315	*3.90*	5.51	15
Mute band	-	-	-	

Remarks: 315Hz is selected because it is located in the peak of weighted curve as well as in linear section of unweighted evaluation curve. Under the proposition that 1kHz reference signal velocity is 7.07cm/s eff. (10cm/s peak), the recorded velocity 3.90cm/s eff. (5.51cm/s peak) at 315Hz is equivalent with velocity 10cm/s at 1kHz in recording characteristic (time constants 3180/318 /75microseconds). In the same way different frequency other than 315Hz can be selected for rumble test. *For example: In JIS C5521-1975 (Testing Method for Record Turntables)" signal lateral 5cm/s peak at 1kHz is selected for both SN measurement and reference tone for checking the cartridge output though it is equivalent to diagonal velocity 3.54cm/s peak (2.5cm/s eff.). When measuring unweighted S/N of same turntable using IEC, DIN, JIS and NAB test records, each indicated SN value should be ranking as IEC>DIN>NAB>JIS because of the velocity difference of the recorded signals.*

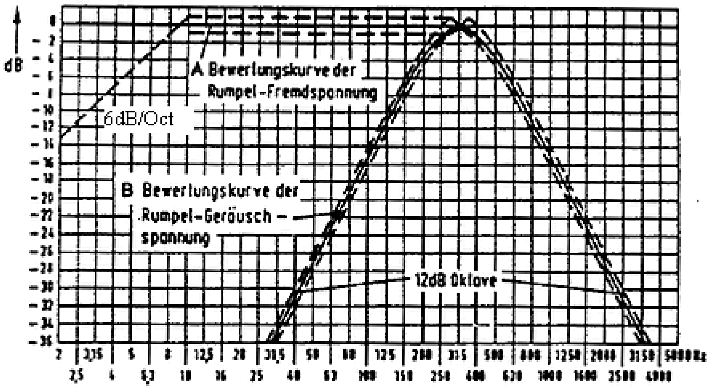
DIN 45539(measuring method)&DIN 45544 (rumble test record) both March 1971 were later accepted as international standards. **Filter for unweighted curve was modified a bit in IEC98-1987 since low frequency resonance between arm mass and cartridge compliance might affect the unweighted measurement.** Left from DIN with my additional remark 6dB/Oct filter versus Right from DIN IEC 98 issued in 1989 as German translation of IEC98-1987. It seems that the subsonic filter of rumble measurement as per IEC98-1987 was made as a compromise between DIN 45539-1971 and JIS C5521-1975 (band-pass filter 300Hz-6dB/Oct & sharp subsonic filter 30Hz 18dB/Oct or 40dB/Oct applying to the output for a plain groove at radius 120mm for LP and at radius 80mm for EP). I make NAB bandpass filter visualised with handwriting. I find a cool passage in this NAB(1964): ***"This measurement is intended to give a measure of electrical effect of the low-frequency noise output of a turntable pickup combination. Since the result depends on the equalizer, pick-up and arm characteristics as much as on the turntable itself, it is not feasible to standardize a turntable alone. The measurement reflects the electrical effect, not the aural annoyance value, of the low-frequency noise. It has been found that strong low-frequency noise at a frequency and intensity below audibility may create severe intermodulation distortion in an audio system, and that in modern systems with extended low frequency response, this may be more serious than the audibility of the low frequency. The reference level of 1.4cm/s peak velocity approximates the expected program level at 100 cps and corresponds in amplitude to 7cm/s peak velocity at 500 cps."*** I prefer the term "SN for a whole system" to "mechanical rumble". Usually weighted S/N only is indicated since its number is around 20dB higher than unweighted S/N. I cannot understand the meaning of weighted S/N since motor rumble & its acoustic coupling to plinth/arm/mat is lower than 315Hz: mostly 10Hz-250Hz after passing **hearing compensation filter (-12dB/octave for 315Hz & up)**-then what is the use of low cut filter from 315Hz? Hence spectrum analysis method has been recommended by some testers (Yamamoto in 1971 & Ladegaard in 1977 etc). Also in IEC98A-1972, beside conventional Method A for general use, Method B applying spectrum analysis instrument was introduced as follows: "*(This method is intended for specialists' use, when an analytical result is required)...By means of a measuring instrument, the voltage Uo produced by the reference signal is measured at the output terminals of the one-third octave filter whose mid-frequency corresponds to the frequency of the reference signal. A search is thus made across the frequency spectrum determined, and for each of the bands concerned, the voltage U at the output terminals of the one-third octave filters are measured and the ratios 20 log U/Uo are determined.*"

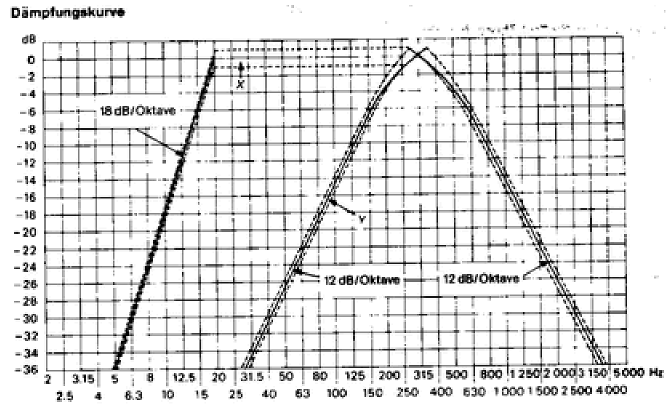
There are two routes of acoustic coupling or feedback within a turntable system: I. motor - driving mechanism - platter - mat - record - cartridge - arm and II. record - cartridge - arm - turntable board/plinth. I & II are in a loop. In my test using stethoscope during playing record I could hear music clearly on arm-base while the noise at spindle was not clear. Sometimes electric transformer produces higher vibration than the spindle of a revolving motor although transformer is suspended by rubber usually.

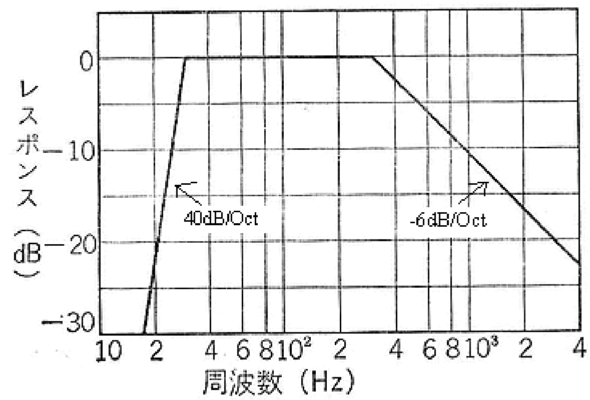
A or x curve to be applied on the output from a mute band: unweighted for 20Hz-315Hz for measuring Rumpel-Fremdspannung=Rumble interference voltage

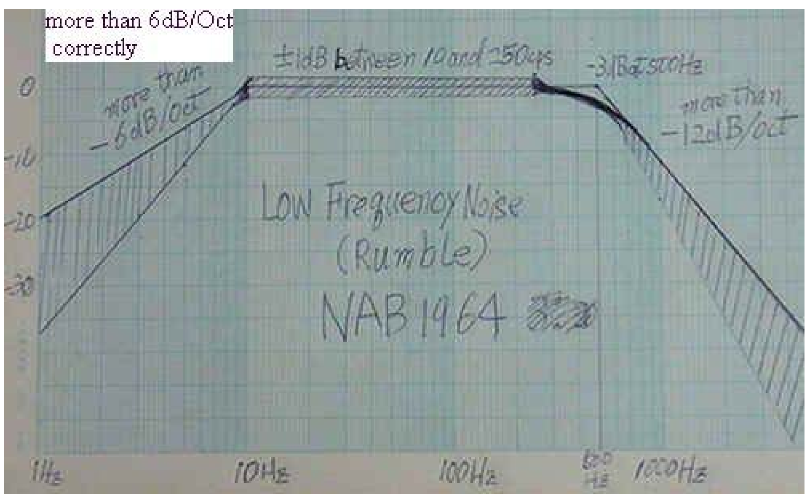
B or y curve to be applied on the output from a mute band: weighted both high and low from 315Hz for measuring Rumpel-Geraeuschspannung=Rumble noise voltage

My note: In these DIN/IEC graphs, symbol +/- for dB/Oct is omitted conventionally.







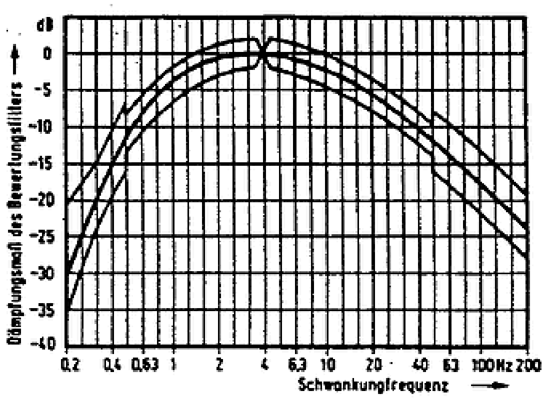


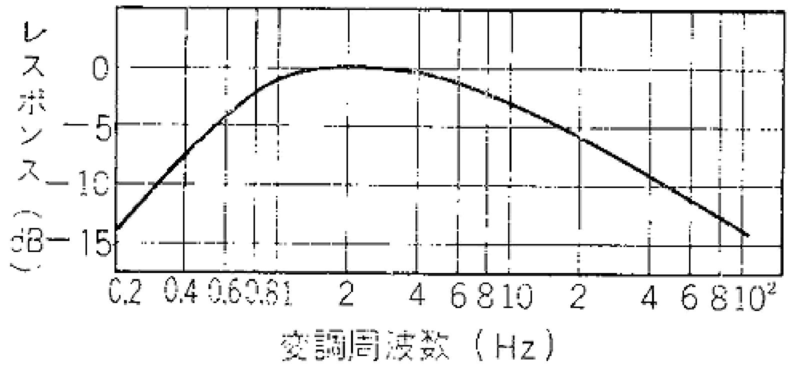
Hum measurement as per IEC98 (1987): Use the same record as the Rumble test (315Hz velocity **5.51cm/sec** using L/R/Lateral modulation) and calculate **The hum voltage ratio =20log10 (cartridge output at 315Hz peak 5.51cm/sec divided by hum induction output) separately for L/R/Lateral.** When measuring hum voltage, the stylus point should be located in the range of radius 5-15cm from the centre of spindle, and the needle should be setting 2.5mm above revolving platter (maybe removing test record from turntable and locating the stylus point virtually at the same level of playing actual records (no mention on record mat). Check the left and right channels and indicate the minimum (= worst value) for stereophonic system. *IMO: The various shielding states of cartridges influence this hum ratio in actual measurements so that hum rate is not specified in recent products. In JIS C5521-1975 (Testing Method for Record Turntables) definitive method for measuring hum induction level using spherical search coil instead of cartridge is presented, but I never know it is applied actually. SN measurement as the result of whole system is already enough though SN ratio is also influenced by actual circumstances such as mat/cartridge/arm/cable/step-up transformer etc besides turntable.*

DIN 45545 (1966):Gleichlauf-Meß-Schallplatten für 33 1/3 und 45 U/min (Wow and flutter test records for 33 1/3 and 45 rpm)

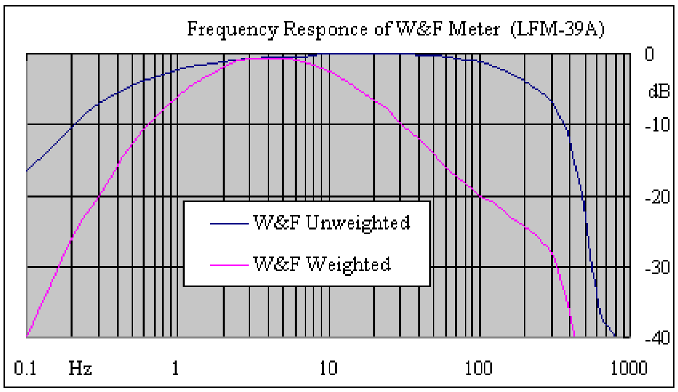
These records are applied for measuring wow and flutter based on DIN 45507(measuring equipment for frequency fluctuation) and DIN 45539(measuring method). Measuring frequency recorded horizontally is 3150Hz. Record itself shall be manufactured within ±0.06% (unweighted about ±0.12%) fluctuation of frequency. And wavy height change hindering optimal centering by means of using the concentric groove shall not exceed 0.3mm. *The test record based on this standard was assigned to DGG.*

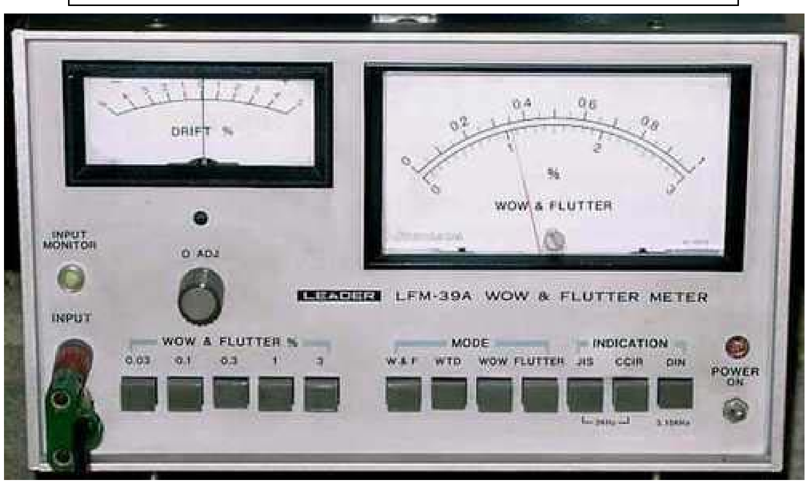
W&F evaluation curves: left as per DIN & right as per old JIS before 1972 for example. By early 1970s, NAB & JIS C5521-1975 adopted DIN/IEC evaluation curve though there *remained(?)* difference in expression among peak/rms/mean. Anyway usual W&F analog meter will rectify the signal (with a special **slow-quasi-peak full-wave rectifier** designed to register any brief speed excursions) so that they have essentially same meaning relatively, only showing different numbers: theoretical rate 1/0.707/0.636 for peak/rms/mean respectively in case of sinusoidal modulating frequency. For example JIS 0.25%rms is equivalent to DIN/IEC 0.35%peak. We cannot compare the measured specifications of equipments without knowing the measuring method and its evaluation curve. Though this measuring method with W&F meter is established and accepted widely, one can doubt its efficiency because it is based on "slow-quasi-peak full-wave rectifier". Also there is **the battle among measuring methods**. J.Mcknight (Ampex) reported in IEEEM (1972) (here the term "flutter" covers wow and flutter): "*The old IEEE/ANSI flutter measurement standard did not predict subjective flutter; it also failed to specify several important characteristics of the meter. Comerci proposed a "flutter index" method but it was never adopted. Results of several workers were incorporated in 1962 in a German Standard (DIN) Weighted Peak Flutter measurement. The NAB flutter measurement of 1965 incorporates the frequency weighting of the DIN Standard, and the volume indicator of Comerci. CCIR adopted the DIN method in 1966. Experiments in the U.S.A. comparing the DIN and NAB methods showed the DIN method to be more satisfactory, and this method is incorporated in the new IEEE Standard 193-1971, based on an IEC draft. Circuits to achieve the desired time and frequency responses are given, as well as suppliers of commercial flutter meters and test records to the new standard.*" Test signal must be recorded laterally because vertical or one channel recording might indicate other factors than wow & flutter of turntable: the movement of stylus on sticky record may be affected more in vertical or one channel recording than lateral recording. In my experience, the wow& flutter values measured on test records are not reflecting the status of wow&flutter in hearing the usual (dirty/sticky) records. Sometimes after cleaning contaminated record and stylus, I find the wow&flutter as well as the amplitude of low frequency resonance is reduced to some extent. Stylus drag cannot be made null in stylus tracing method, but it can be reduced to some narrow range after cleaning records. Hence load specification 80g for instance in direct drive turntable is of no importance. Even if the turntable is rotating at constant speed under fluctuating load (random frictional forces) by the stylus drag, the movement of stylus is nevertheless affected by the stylus drag itself. This aspect of stylus/cantilever movement is often called as "stick-slip behavior/motion".





Example of unweighted & weighted filters (Leader LFM-39A manufactured in 1979 so that filters are same as DIN):





Specifications of wow-flutter meter for example				Band-pass Filters : Unweighted	
Standard	Hz	Value	W&F range	HPF	LPF
NAB	3k	Mean	0.5-200Hz	0.5Hz 6dB/Oct	200Hz-15dB/Oct
JIS	3k	RMS	0.5-200Hz	0.5Hz 6dB/Oct	200Hz-15dB/Oct
CCIR	3k (3.15kHz)	Peak	0.3-200Hz	0.3Hz 6dB/Oct	200Hz-15dB/Oct
DIN	3.15k	Peak	0.3-300Hz(0.3-200Hz)	0.3Hz 6dB/Oct	200Hz-15dB/Oct
IEC	3.15k	Peak	0.3-200Hz	0.3Hz 6dB/Oct	200Hz-15dB/Oct

My note on conventional W&F meter. Why fundamental 3kHz or 3.15kHz is selected? It is said that the sensibility peak of human ears is located around 2kHz-3kHz. Moreover if fundamental frequency is nearer to modulating frequency, then more sharp LPF is required otherwise W&F 0.1% (-60B) cannot be measured. The reason why modulating frequency upto 200Hz is enough might be another story (acoustic psychology). The acoustic psychology (tests carried out by Eberhard Zwicker in 1952 and NHK in 1955 etc) tells us that human ears are most sensitive to wow (modulating frequency) 3-6Hz so that weighted curve for hearing compensation is decided. Upon my hearing of FM waves generated experimentally, even through PC speakers I can hear clearly WOW of 3-6Hz upto -50dB=0.3% as something like beating echo sound while I could not discern W&F of any frequency at less than 0.1% - thus I can reconfirm conventional theory: "there is no real problem in sound quality as far as continuous W&F (excluding any peaked thrust from groove irregularity) is lower than 0.1%". **I suppose this is the reason why IEC recommends groove eccentricity to be within 0.2mm. Wow caused by 0.2mm eccentric groove: 0.14-0.33%**

for music band for LP can be reduced to less than 0.1% weighted with hearing compensation=1/3(-10dB at 0.55Hz according to chart). The minor frequency difference between 3kHz and 3.15kHz is negligible because the filter band of W&F meter can handle centre frequency +/- 10% as input. Usually the measured figures weighted with hearing compensation (evaluation curve) is indicated as representative value. When the frequency counter is mounted with W&F meter, counter shows centre frequency so that it works as drift meter (indicating average frequency in certain time scale: drift between playing outmost groove and inmost groove) : to know actual rapid frequency variation, frequency counter with smallest "gate time" is required. Some W&F meters can indicate W&F unweighted/W&F weighted/Wow/Flutter separately in combination of indication JIS/DIN/NAB etc. 0Hz-6Hz as wow and 6-200Hz as flutter in many conventional W&F meters (when modulated with threshold frequency 6Hz and 1% amplitude, meter shows 0.7% each for wow and flutter). Meanwhile current IEC calls 0.1Hz-10Hz as wow range and over 10Hz as flutter range. Now IEC standard based on DIN remains valid while JIS is abolished as standard. **Nobody care about the end of standards**: almost all JIS standards about analog records and equipments were stamped as "abolished" with specific dates while some old standards are walking alone as living ghosts without knowing their death. IEC would adopt 20 years rule from last revision then IEC98(1987) too becomes such living ghost.

DIN 45549 (1980):Abtastfähigkeits-Meßschallplatte (Tracking ability-test-record)

Object: In the first place this test record shall be applied for trackability test at 315Hz and 10kHz. It covers supplementary tests for trackability in mid frequencies for FIM measurements, sensitivity and rectangular modulation. Vertical modulation angle is 23degree for stereo recorded bands except B9-B16 monaural bands which are recorded laterally/sidewise=**Seitenschrift**. Bands A1-A2: 1kHz effective velocity 5.6cm/sec(=peak 8cm/sec) as reference tone, Bands A3-A7: pulse 10kHz with a 250Hz repetition, peak velocity 8-20cm/s interchanging between L/R for pulse test. Bands A8-12: 300Hz/3000Hz (4:1), 300Hz component peak velocity 4-10cm/s interchanging between L/R for frequency intermodulation test (each 2.5dB up for 400/4000Hz when playing at 45RPM instead of 33.3RPM)- see DIN 45542. Bands B1-B2: 1kHz effective velocity 5.6cm/sec(=peak 8cm/sec) as reference tone. B3: Rectangular wave 1kHz cut as triangle with amplitude 11µm. B4-B8: complex (Doppel) tone of 1.8kHz+2.2kHz (1:1) momentary peak velocity 10-25cm/s interchanging between L/R. Bands B9-16: 315Hz peak signal amplitude 50µm-120µm. Distortion rate in high frequency is measured with pulse 10kHz/250Hz while trackability in low frequency is measured with high amplitude horizontal recording of 315Hz. The distortion for high frequency after passing special filter shall be Dh=U(250)/U(10000) x 100 in %. I saw similar equation in leaflet attached to Shure Test-record TTR-103 (45rpm) (10.8kHz pulsed high frequency test with a 270Hz repetition). In low-frequency test Shure TTR-103 indicated Amplitude Intermodulation Distortion with 400+4kHz at 45rpm based on SMPTE (Society of Motion Picture & Television Engineers) method. Quite different measuring methods for IMD measurement are imaginable: record Pink Noise excluding certain bandwidth and compare it with reproduced output range to measure distortion fallen in the band. *Simple method for measuring tracking ability was once indicated by IEC98A in 1972 which defined the tracking ability as the minimum tracking force required to maintain contact between reproducing stylus and both groove walls on a given test record having "the average recorded levels found on disk records"(45 degrees R or L one channel sweep 80-8000-80Hz: max 18cm/s peak around 2kHz) I imagine two objections: 1) The cartridges with highest compliance and lowest VTF are not always having highest tracking ability. In my diabolic definition: High-compliance cartridge is a type of cartridge which cannot endure drastic change of VTF. 2) What are the average recorded levels? Practically for tracking ability test, some audiophiles use the specific bands of commercial records which contain the difficult part (mostly high frequency & high amplitude passage with sibilant sounds) for cartridges. Hence the tracking ability tests are developed to more complicated methods maybe based on Shure: "A Practical High-Frequency Trackability Test for Phono Pickups" JAES in April 1972 etc. IMO: Tracking ability test in 98A in 1972 was based on average (its moderate intention is known from test record size 7inch and speed 33.3rpm) while the advanced methods are based on the extremity (as some audiophiles demand). Once I found difficulty in obtaining average performance reproducible everywhere & anytime as some old British Standards (rpm of car engine) require, whereas other standards allow to indicate maximum performance under optimum or optional condition. I don't know which is more user-friendly, but audiophiles are usually fond of extreme rate.*

***Current IEC 60098 Clause 14.9 Trackability** is suggesting to use three kinds of test signals:*

-A. Trackability at low-frequency with 315Hz/Horizontal Modulation. Its performance is indicated by max. amplitude in mm up to which a cartridge at recommended tracking force can trace without apparent distortion and tracking problem. The smaller rate of amplitude shall be adopted when the performance differs between channels.

-B. Trackability at low-mid frequency with sweep from 1kHz to 20Hz/Horizontal Modulation. The output of these frequencies are equalised with IEC/RIAA reproduction characteristics so that the output voltage is stable within these frequencies. Hence velocity shall be indicated along with respective frequency measured. Its performance is indicated by max. velocity in cm/s up to which a cartridge at recommended tracking force can trace without apparent distortion and tracking problem. The smaller rate of velocity shall be adopted when the performance differs between channels.

-C. Trackability at high-frequency with pulse 10kHz (with repetition at 250Hz) LRLRLRLRLR. The output is amplified linearly and then filtered into components. Its performance is indicated by max. velocity in cm/s up to which a cartridge at recommended tracking force can trace without excessive distortion and tracking problem. The smaller rate of velocity shall be adopted when the performance under the specified distortion rate differs between channels. Also distortion rate in high frequency shall be indicated. Why impulse instead of continuous 10kHz recording? I suspect that continuous 10kHz recording at very high velocity can burn out driving coils of cutterhead as specified by Neumann SX-74 with cutter drive logic SAL74 as under. Lateral 28.5cm/s peak can be converted to stereo (45 direction) around 20cm/s peak. Even if juvenile cutting engineers fumble with Neumann and try to record continuous 10kHz 20cm/s, the cutting system can remain undamaged as far as cooling equipment is added.

Maximum velocity (lateral cut)

at 10 kHz continuous operation		
without cooling	16 cm/s ≙	1,3 A
with cooling	28,5 cm/s ≙	2,3 A
Tonebursts (10 kHz) 10 ms Impulse	105 cm/s ≙	8 A

Band	Kind of Recording	Effective value cm/s	Peak value cm/s	REMARKS
How to use this test record: linear flat amplifier (without RIAA/IEC reproducing characteristics) should be used.				
Side A: Tracking Ability Test Record as per DIN 45549: *A test record based on this standard was produced by DGG.*				
A1	Left Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
A2	Right Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
A3	L/R	5.6	8	**Impulse Test 10kHz with repetition at 250Hz**: (every packet of impulse: 8wavesx10kHz+mute=10kHz0.0008**s**＋mute0.0032s) L/R interchanging every 20 seconds
A4	L/R	7.1	10	
A5	L/R	8.8	12.5	
A6	L/R	11	16	
A7	L/R	14	20	
A8	L/R	2.8	4	**FIM (frequency intermodulation) Test 300/3000Hz (4:1), the velocities of 300Hz component are as indicated in left column.** L/R interchanging every 12 seconds for 33 1/3 rpm *By rotating at 45rpm, test signal approx. 400/4000Hz and L/R interchanging every 9 seconds [EP/LP=rpm ratio 1.35, 1.35x300Hz=405Hz]*
A9	L/R	3.5	5	
A10	L/R	4.5	6.3	
A11	L/R	5.6	8	
A12	L/R	7.1	10	
Side B: Tracking Ability Test Record as per DIN 45549: *A test record based on this standard was produced by DGG.*				
B1	Left Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
B2	Right Channel	5.6	8	Reference Tone Level = 0dB 1kHz 15seconds
B3	L/R	Rectangular wave 1kHz cut as triangle shape in groove with amplitude 11µm. L&R each 15seconds		

B4	L/R	7.1	10	**Difference Tone Test by 1.8kHz+2.2kHz (1:1)** L/R interchanging every 12 seconds
B5	L/R	8.8	12.5	
B6	L/R	11	16	
B7	L/R	14	20	
B8	L/R	18	25	
B9	Lateral	*7.0*	*9.9*	315Hz peak amplitude 50microns (displacement 0 to peak)
B10		*8.4*	*11.9*	315Hz peak amplitude 60microns (displacement 0 to peak)
B11		*9.8*	*13.9*	315Hz peak amplitude 70microns (displacement 0 to peak)
B12		*11.2*	*15.8*	315Hz peak amplitude 80microns (displacement 0 to peak)
B13		*12.6*	*17.8*	315Hz peak amplitude 90microns (displacement 0 to peak)
B14		*14.0*	*19.8*	315Hz peak amplitude 100microns (displacement 0 to peak)
B15		*15.4*	*21.8*	315Hz peak amplitude 110microns (displacement 0 to peak)
B16		*16.8*	*23.8*	315Hz peak amplitude 120microns (displacement 0 to peak)

DIN 45550 (1976):Schallplatten-Hüllen; Außen- und Innenhüllen, Maße und Beschriftung (Record sleeves; outer-and inner-sleeves, dimensions and inscription) & **DIN 45551 (1976): Schallplatten-Kassetten für 30 cm-Schallplatten; Maße und Beschriftung (presentation-box for 30cm-record; dimensions and inscription)**

The German people really likes norms - I never imagined such specifications were existing. Jacket size for LP is width315xheight311 with side opening (inner thickness 2mm). Basic inner sleeve for LP is almost square(w309xh304) with circular cut for label. DIN 45536(Mono 17cm)/45546(Stereo 17cm) &45537(Mono 25/30cm)/45547(Stereo 25/30cm) are quoted as specifications of records though sleeve for 25cm records is not specified (maybe by 1976 the production of MP=medium play records is much reduced). See also my Japanese page about jacket, inner sleeve & box.

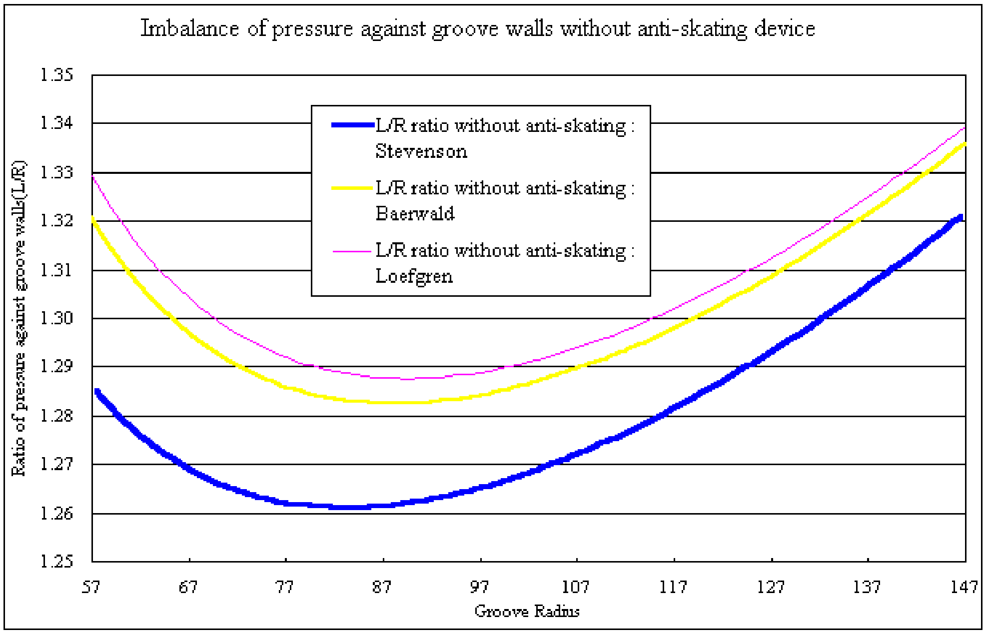
My Summary Note:

These industry standards (IEC/DIN/NAB/JIS) cover almost all the products specifying minimum requirements for not only soft but mainly reproducing equipment available at the times. Hence their specifications don't tell anything new/essential on music recorded groove radii. One thing I feel curious in IEC60098(1987) is about inner groove radius 63.5mm which is related to the performance of automatic player (my Kenwood P-5E Linear Tracking Player will lift arm around 60mm radius before finishing groove located around 54mm radius). In 1987 when CD players became already popular, it might be thought that record players could be also automated as seen mostly in low and middle price range of record players.

It seems funny to me that some long time play-back records have not utilized inner radii to maximum. For example, one EMI/Seraphim record: Schubert String Quartet No. 14(Death and Maiden)=38min26sec on one side (pseudo-stereo made from monaural recording) and Piano Quintet (Trout)=32 minutes on other side (both inmost recorded radii are larger than 70mm). Usually it is said that LPs have 150-300 grooves per inch. Hence when music band width is max 83mm(146.5-63.5) then 490-980 grooves for 15-29minutes. The above EMI/Seraphim case: 38min26sec/75mm=about 433 grooves/inch - too fine pitch! I suppose that this record has not utilized extreme inner groove radius in order to avoid (expected) inner tracing distortion by the sacrifice of out-put level (dynamic range and S/N).

Lateral Tracking Error and its distortion: it might be critical (audible) only with recent elliptical/line contact tip in stereo groove esp. if anti-skating mechanism is not equipped on overhang-offset arm. With spherical tip in monaural groove, its distortion is not so critical even without anti-skating mechanism (or other distortions due to spherical tip are enough to mask this relatively small distortion?). Considering the inner groove is rarely less than 70mm for LP and if the inmost music groove radius is 63.5mm and outmost music groove radius is 146.3mm, an optimum arm design based on Baerwald method can be as follows: Linear Offset for Baerwald method i.e. peak distortion rating similar at 63.5/88.561 /146.3mm is 96.04mm (instead of current Baerwald type linear offset around 93.5mm)
Null points: 69.2/122.8mm (instead of current Baerwald type null points: 66/120.9mm)
In comparison with current Baerwald type, this new design has wider offset angle and also *increased overhang (hence higher anti-skating force required to mate with increased side thrust force)*.

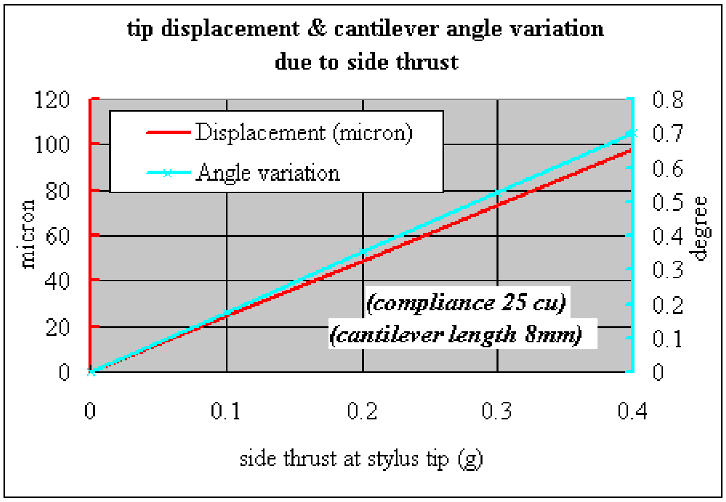
Anti-skating mechanism is problematic. It is rare that the anti-skating force will match side thrust force due to eventual friction forces. Some Thorens arms have 4 different scales for anti-skating: wet/dry x spherical/elliptical tip. The following graph shows imbalance of pressures on flank L/R for three representative designs of geometry (Stevenson/Baerwald /Loefgren) when anti-skating device is omitted (parameters: *effective* coefficient of stylus drag 0.3 and effective length of arm 231.2mm).
Note: theoretically the true coefficient of friction = 1/(SQRT(2)) of the measured or empirical value since vertical stylus pressure is to be divided *statically* into VTF/(SQRT(2)) each on groove flank. Then stylus drag force is [VTF/SQRT(2)]*2*coefficient of friction=VTF*SQRT(2)*coefficient of friction. ***This tricky calculation is based on armchair theories*** because the VTF cannot be actually divided evenly during stylus drag. Hence usually effective coefficient of stylus drag *as empirical results* is assumed to be *theoretically* equivalent to SQRT(2)*coefficient of friction. This coefficient of stylus drag 0.3 (coefficient of friction 0.212) for example is rather too small in comparison to the past investigations (coefficient of stylus drag 0.27-0.5 by Rangabe or **0.25-0.55 by JVC-1979 as shown in the following table**). The *dynamic* load of stylus pressure on the groove is never constant. **Many factors are involved in the nature of stylus drag: stylus contact profile and record elasticity (depth of stylus dipping into groove wall by VTF - see my stylus.xls), groove modulation amplitude and frequency, mechanical impedance of stylus movement corresponding to such groove characteristics, and mostly the dusts and sticky matters on contaminated records and stylus tip.**



The following rates seem to be indicating stylus drag coefficient instead of coefficient of kinetic friction : does it mean "stylus drag coefficient" as empirical value obtained from measurements?			
Groove modulation	Spherical tip (17μ)	Elliptical tip (7x17μ)	Shibata tip (7x65μ)
Mute plain groove	0.25	0.3	0.28
3〜10cm/s	0.3	0.4	0.35
8〜16cm/s	0.45	0.55	0.5
30kHz 5cm/s	0.4	0.5	0.45

Note that the deflection of cantilever due to the side thrust force (skating force) is too small that one cannot adjust anti-skating force seeing the deflection of cantilever (see the following drawing and think coolly on the normal human eyesight). When we recognise apparently cantilever deflection during playing a record, then it has a defective cantilever or anti-skating force is too high. Hence both Dual Skate-0-meter and Orsonic Lateral Pressure Detector were invented as magnifying device to see cantilever deflection. Lehmann and Harnisch invented Dual "Skate-0-meter" and commented in their US Patent 3328037-1967: "*To permit accurate adjustment, hitherto a record was used which had no grooves but only a smooth surface. The pick-up with its scanning needle was placed on the rotating disc and the antiskating so adjusted that the pickup remained stationary. Investigations have proved that this method is only apparently accurate. The actual friction of the scanning needle in a sound groove is different. Direct measurement of this friction, which as such gives a direct measure for the necessary anti-skating force, is however relatively complex.*" And they recommended to apply Skate-0-meter on a plain groove with normal recording pitch while Nakatuka in his USP4183537-1980 recommended to apply Orsonic Lateral Pressure Detector on sound grooves for anti-skating adjustment. Also note that usually the bottom profile of stylus is unspecified or unpolished since such part of stylus is designed simply to have enough clearance from the bottom of groove. The higher stylus drag for higher frequency and higher amplitude can be attributed to the mechanical impedance of respective pick-up. In order to move stylus in higher frequency, there arises instantaneous higher stylus pressure to groove walls as reaction from undulating walls. Thus effective low mass or low inertia of moving parts is required for tracing such high frequency recorded groove with relatively light stylus down-force. Mechanically a pickup has three different (stiffness or compliance/resistance/mass or inertia) controlled domains in mechanical impedance curve. Typically: stiffness controlled domain (20Hz-1kHz* see note), resistance-domain (1kHz-10kHz or around) and mass- or inertia-domain (around 10kHz and upward) though its domain and curve of mechanical impedance (dyne sec/cm) is shifting up or down as per the make and design.

**Note: "Compliance at 100Hz" in the specification for some Japanese cartridges must be considered in this lower frequency range. It is often misunderstood as if it would be intended for some calculations at arm-cartridge resonance around 5Hz-20Hz. In fact it indicates an index convertible to a mechanical impedance at lower frequencies for the purpose of obtaining the vertical stylus pressure required for safe tracking. It is concerned with tracking ability and not with resonance. Hence it is of no use for amateurs who try resonance calculation. Frankly speaking the required VTF value instead of compliance value is enough for users. Since 1970s Shure has not indicated "misleading" compliance value, but instead indicating VTF value sometimes together with trackability chart (max. traceable velocity [cm/s] per frequency under specific VTF). The mechanical impedance [dyne sec/cm} chart for full frequency range (technically equivalent to Shure trackability chart) is more important than compliance at lower frequencies. Please see the relation among mechanical impedance, compliance and recorded velocity as explained in technical sheet attached to DENON test record XG-7001. By measuring the mechanical impedance, it is possible to know the stylus pressure required for tracing on specific velocity of record. Think on the relation between Shure trackability chart and Denon mechanical impedance chart i.e., between velocity and VTF. Naturally it is concerned with the recordable and recorded velocity on actual records.*



BTW: There is no effective measuring method for distortion due to lateral tracking angle error because this kind of distortion is usually masked by much bigger distortions (i.e. tracing distortions) when tracing actual record with a stylus tip of considerable contact radii. Also read the end of this page about the comparison of various distortions. Generally tracking (angle) error distortion is in small order (less than 2%) in comparison with tracing error distortion (often exceeding 10%) due to effective contact radius of stylus tip. Hence in order to check angle error and alignment it is of no use to see playback wave forms on oscilloscope since distortion rate ascertainable on oscilloscope should be more than 10% otherwise not easy to find as a distortion or deformed wave. Actual *impulsive* mis-track (stylus skipping from groove walls mainly due to defective groove or dirty sticky stylus) can be seen on oscilloscope or heard very cruelly with our ears.

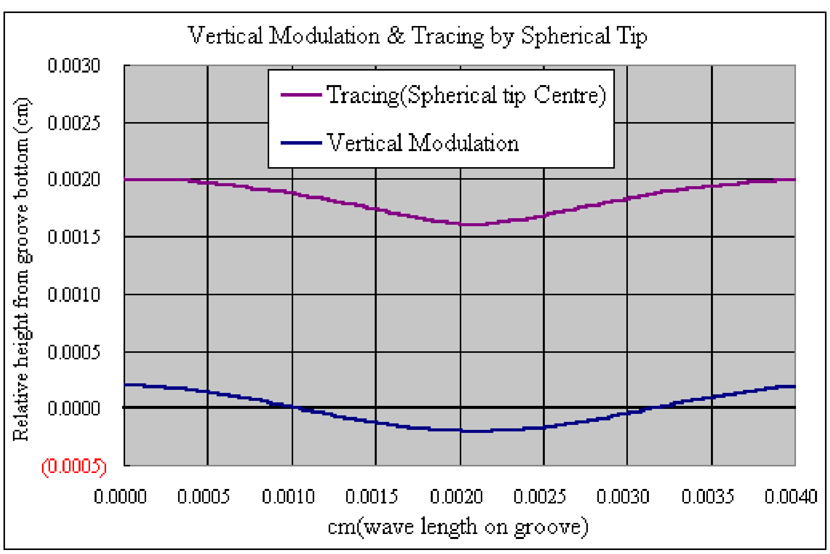
According to the AES report in 1968 by Toshiba engineers: "Trackability Test by Complex Tones and Biasing Force Effects of Phonograph Pickups": "*Some of the so-called "high compliance" cartridges have produced larger I.M.D. under the specified tracking force than those of relatively low compliance. For low modulation level both cartridges have similar characteristics, but for high modulation level the former are much effected by side thrusts. Side thrust less than 0.05g is allowed for I.M.D. less than 10% for high compliance cartridges. From this, "high compliance" cartridges operating under small tracking force are not necessary good from the viewpoint of degradation by biasing forces*".
In JVC book(1979), Shibata as one of the writers commented as follows: "*Cantilever deflection can reach more than a few degrees by side thrusts so that tracking angle error distortion is increased. To avoid such occurrence, the compliance should be kept not excessively high, and linear tracking arm (not swinging but linear shifting) is preferable*". IMO: Deflection of "a few degrees" is contradicting to above drawing, but under certain stress loading for long time, cantilever may be deflected and not reverted to the normal position (permanently deformed damper). In my experience, high compliance cartridge with soft damper tends to bent its cantilever angle after long use: outward bent under 0 anti-skating force, inward bent under excessive anti-skating force. It is not easy to know the actual operating angles in both antiskating bias and tracking angle adjustments though some audiophiles are fond of such adjustments based on some devices. I find some cartridges having the cantilevers not located in the centre from the first.

There are various distortions peculiar to Stereo LP records

How stand the relative rates among these distortions? **If you are interested in the equations for the following simulations, please download my EXCEL file and check by yourself.**

Due to different styli shapes between cutter and reproducer etc

A. Vertical Tracing Distortion (mainly 2nd harmonic at 1kHz, 3rd harmonic increases at 10kHz). The following graph indicates the trajectory of spherical 18micron tip centre on sinusoidal vertical modulation at velocity 6.3cm/s, groove radius 6cm, frequency 5kHz. *I would not like to perplex audiophiles, but true to my mind I try to explain: THERE IS A LONG LONG HISTORY IN RECORDING: At first Vertical monophonic Phonograph cylinder (1877) Next Lateral monophonic Gramophone record (1895)/Monophonic LP record (1948) & 45 rpm record (circa 1949). Experiments of V/L two channels recording were finally abandoned by the end of 1957 though V/L mode was once thought easy to be realised as additional V or L modulation to another. Frederick Vinton Hunt (1905-1972) wrote together with his colleague J.A. Pierce: "On Distortion in Sound Reproduction from Phonograph Records" J.A.S.A 1938 a monument paper simulating various phonograph distortions. W. D. Lewis and F. V. Hunt: "A Theory of Tracing Distortion from Phonograph Records," J.A.S.A. 1941. These researches led to the development of criteria that eventually made possible the long-playing record. If L/V (H/V) stereophonic mode is realised, there arises a quality difference between channels because vertical tracing distortion is higher (almost double) than horizontal/lateral distortion. Hence 45/45 stereophonic mode was standardised around 1958.*

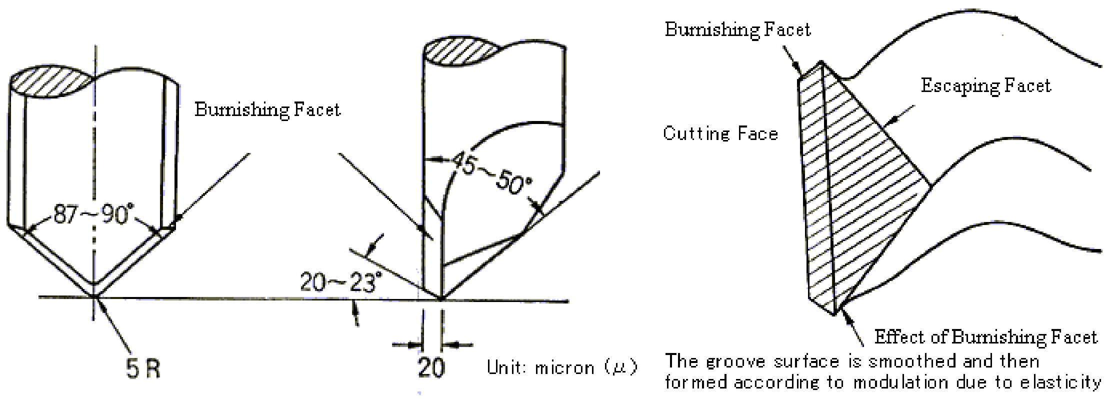


B. Horizontal Tracing Distortion (mainly 3rd harmonic distortion) due to different styli shapes between cutter and reproducer.

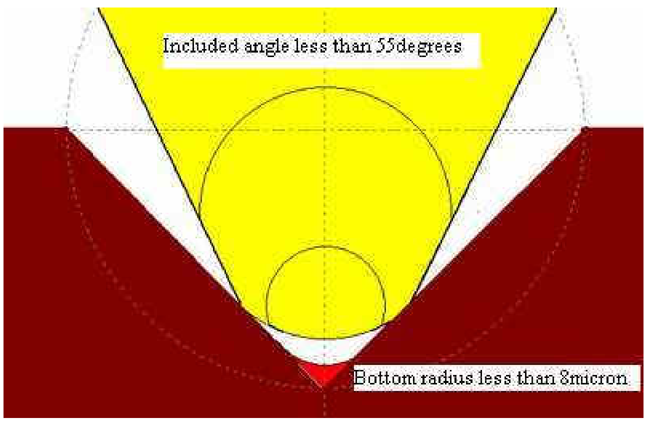
These (A&B) can be improved by making tip radius smaller. IEC98(1987) specified groove dimensions: top width 30micron min. bottom radius 8micron max. The clearance between the stylus tip and bottom of the groove shall be 0.002mm min and the stylus tip shall not touch the groove edges. In order to get such clearance from groove bottom and edges, the appropriate radius of spherical tip shall be limited to 0.5-0.8mil (13-21micron).
The effective (contact with groove flank) radius of curvature of elliptical tip is 0.2-0.4mil while its radius toward bottom is more than 0.7mil (18micron). But too small spherical tip may dig the dusts in the bottom of groove so that it tends to be noisy.

The appropriate spherical tip radius depends on the dimensions of groove modulation				
		IEC98(1958)	IEC98(1964)	IEC98(1987)
1	groove bottom radius	<7.5micron	<4micron	<8micron
2	bottom clearance	nil	nil	>2micron
3	top width*	>55micron*	>51micron*	>30micron
4	included angle of spherical tip	40-50degrees	40-55degrees	<55degrees
top width* is applicable for monophonic only. In DIN 45547 Stereophonic disk records St33(1981) top width average 35micron, momentary value 25micron				

Example of cutting stylus for fine groove: this example is obsolete. Current cutting stylus has the burnishing facet width less than 5micron for lacquer cutting (no burnishing facet for copper cutting). Bottom radius of cutter should be also less than 5micron.



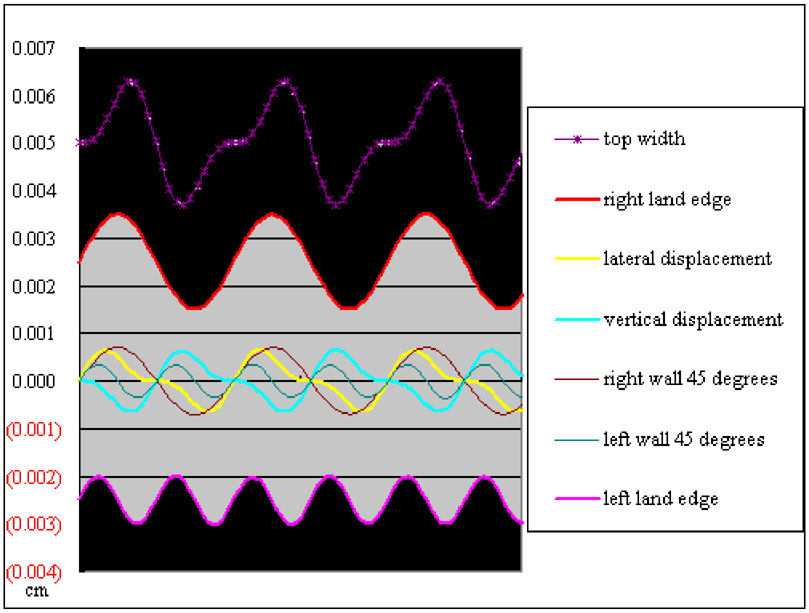
Spherical Tip on Fine Groove: Strictly speaking not spherical because it has included angle less than 55degrees in order to reduce pinch effect to some extent (about 40% less as compared to true spherical ball tip).



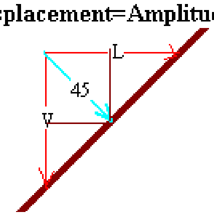
There are various methods for finishing spherical tips from conic shapes. In short: If the included angle of cone is less than 55 degrees from the first, then only the bottom point of tip is rounded to specific radius simply. In case of making elliptic tip from cone, the included angle of cone more than 55 degrees and "not more than 60 degrees" as per USP 3292936-1966 by Grado is also used. JIS S8516-1976 (Stylus) described as follows: "sapphire or block diamond type stylus should have the included angle 40~55 degrees while bonded diamond type can have the included angle up to 60degrees avoiding dropping the tip due to the small area for bonding a tip on the metal base."

Applied maximum spherical tip radius is half of minimum top width of groove
tip radius 76micron (3mil) : minimum top width about 152micron for monophonic coarse groove (SP)
tip radius 25micron (1mil) : minimum top width about 50micron for monophonic fine groove (LP)
tip radius 18micron (0.7mil): minimum top width about 35micron for mono&stereo fine groove (LP)
tip radius 15micron (0.6mil): minimum top width about 30micron for mono&stereo fine groove (LP)
tip radius 13micron (0.5mil): minimum top width about 25micron for stereophonic fine groove (LP)
This table will not indicate actual tip radius or groove top width. My intention is to show the relation between applied stylus radius and groove modulations i.e., in order to land spherical tip on 60~70% height of the groove walls for respective minimum top width (hence I underlined maximum and minimum). About various top width, please look into Standards Table and JIS S8502-1973.

Sample of stereophonic groove: please note that top width of stereophonic groove is changing momentarily and that the minimum top width is depending on the displacement (amplitude) and the nominal top width of plain groove - see my excel file for simulation which is made originally for my understanding 90 degrees recordings (stereophonic 0/90=L/V mode or 45/45 mode - currently only 45/45 mode is adopted for stereophonic recording and reproduction). Specific to stereophonic groove of 45/45 degree modulations, the amount of lateral displacement is always same as that of vertical displacement irrespective of amplitude and frequency differences between channels. Hence cartridge to trace such groove should have same compliance laterally as well as vertically - however lateral compliance is usually higher than vertical compliance in most stereophonic cartridges. *In practice the stereo grooves are cut with various kinds of limiters. In US Patent 3013125 (Stereophonic Recording) Goldmark referred to such limiter: "Normally, these two signals [sum and difference] are of similar amplitude and it is difficult to design a pickup which will follow them without generating distortion. We have discovered that the difference signal can be limited in amplitude so that it will be as little as one-half that of sum signal, or less, without impairing substantially the stereophonic character of the recorded information."* Sum component (lateral displacement) is in phase portion & Difference component (vertical displacement) is out of phase portion between each signal in Stereophonic two different sounds in 45/45 mode. In case of playing compatible discrete 4 channel records, same compliance for both lateral and vertical directions was demanded for pick-up cartridge. In case of playing usual stereophonic grooves cut with such vertical amplitude limiter (i.e. depth control), the imbalance of cartridge compliance for lateral/vertical directions did not become any serious problem since stereophonic groove in practice was a gimmick or the product of compromises from the outset!

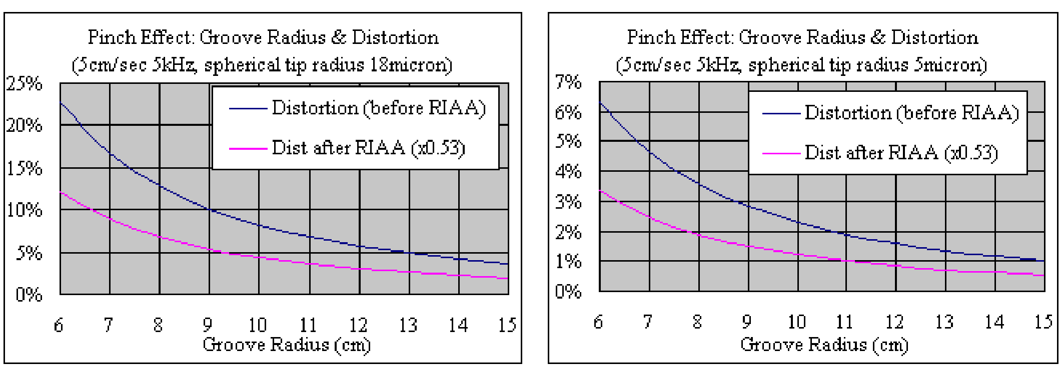


Displacement=Amplitude

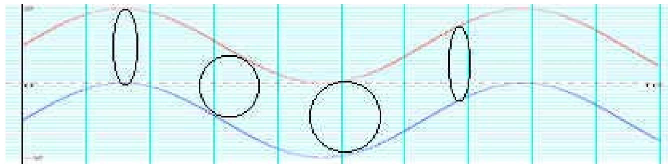


	Lateral Component	Vertical Component
Monophonic modulation	100%	0%
Ideal stereophonic modulation	50%	50%
Practical stereophonic modulation	70%	30%

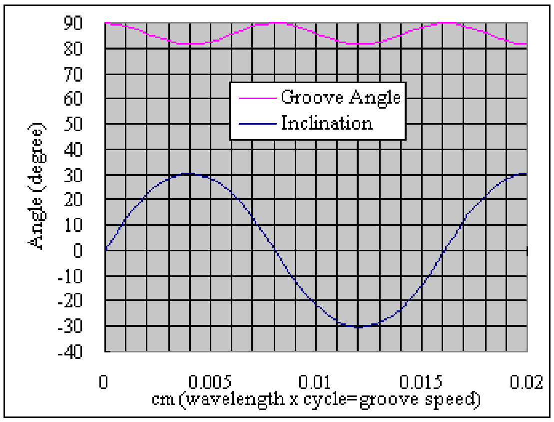
There is a distortion toward inner groove namely "**pinch effect**" which can be reduced by using elliptical tip. This effect may cause vertical modulation of double cycle. In case of fundamental 5kHz lateral recording, the cycle of vertical modulation due to pinch effect is 10kHz. If cartridge has same compliance for vertical and horizontal movement, then the distortion due to pinch effect shall be approximated as shown in following graphs. Here the distortion ratio % is calculated as Vertical velocity (arising from pinch effect) divided by Lateral velocity of the recorded signal. *Though this pinch effect is not counted as tracing distortion usually, its nature (2nd HD) looks like a variant of vertical tracing distortion (2nd HD) in spite of original lateral groove modulation. Pinch effect to a considerable extent can occur also in actual stereophonic groove modulations which contain larger part of lateral (sum) component as Goldmark suggested.*

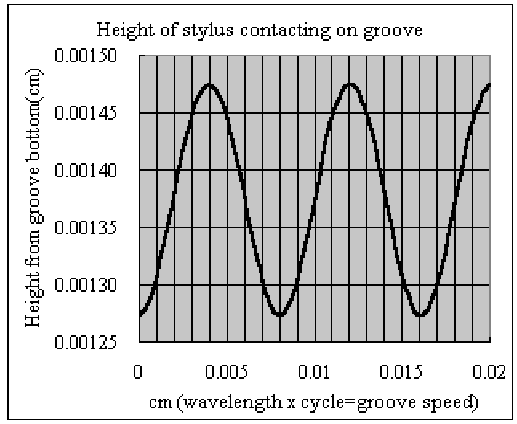


Schematic of 1.3kHz Lateral Modulation at groove radius 6cm, displacement peak to peak 30μm: velocity about 12.25cm/s (**velocity=2πfa** where f=frequency, a=displacement of 0 to peak)

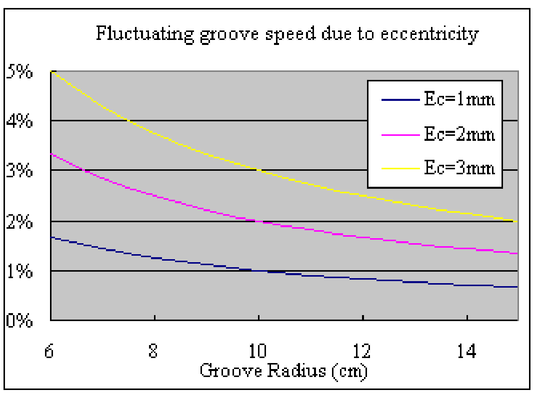


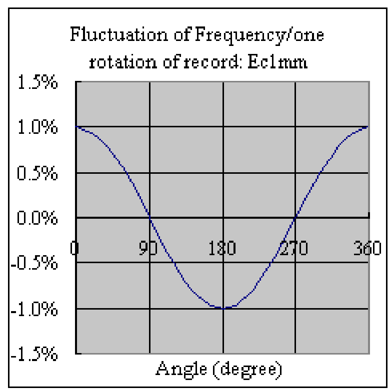
At tracing the above groove with spherical tip radius 18micron, the inclination of modulation corresponds with that of points of contact of spherical tip on flanks. Pinch effect eminent toward inmost groove radius is additional vertical modulation arising from original lateral modulation of high velocity/frequency. In this case, vertical output calculated (1micron x 2f)/(15micron x 1f) is 13.5%(-17dB) of lateral output.



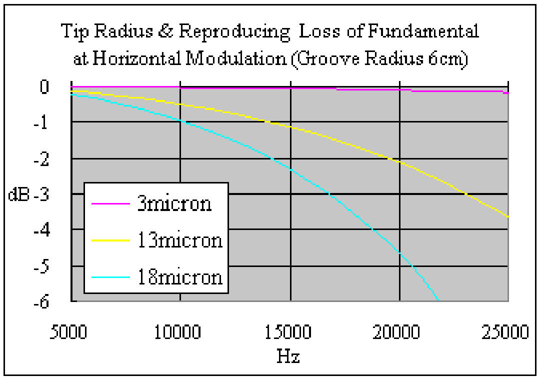


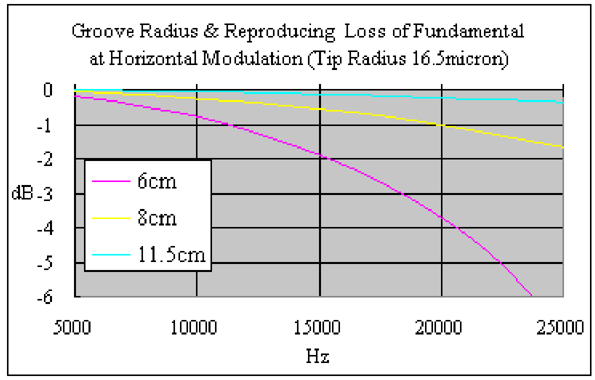
There is an additional distortion（similar to Wow=fluctuating groove speed±%) due to eccentric groove or hole which happens to be displaced more than 1mm sometimes. Right graph shows Fluctuation of Frequency at groove radius 10cm with eccentricity 1mm where pitch (groove speed) fluctuates +/- 1% per rotation=1.8sec in case of 100/3rpm (200degree/sec) from recorded frequency. Thus the rate 0.5555cycle(=once per 1.8sec) indicates modulating frequency (FM). Additional amplitude modulation (AM) if any due to this displacement is rather small (max 0.35cm/s at 1mm displacement of hole) and harmless since this amplitude of 0.5555Hz can be usually suppressed with filter and compliance of cartridge as far as arm pivot has high sensitivity to follow this displacement smoothly. Meanwhile frequency fluctuation (FM) shall remain uncompensated with any filter.





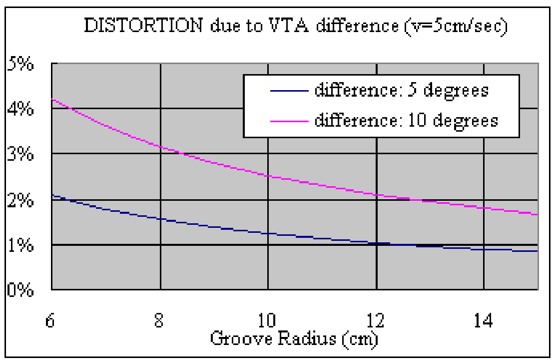
There is still another kind of distortion: Reproducing loss of fundamental at higher frequency depending on tip radius & groove radius & amplitude of recorded level. **The frequency response of high frequency is usually measured at outer groove radius and the recorded level (amplitude) for frequency response test is lower than reference tone level** (see DIN 45543 test record etc). Lateral modulation at outer groove radius 11.5cm shall mean groove velocity around 40cm/s where this loss is almost negligible. Graphs show loss at lateral modulation: *constant* velocity 5cm/s peak (*flat* recording without RIAA recording emphasis). Vertical reproducing loss is almost twice lateral reproducing loss.
Percy Wilson commented in his book "THE GRAMOPHONE HANDBOOK" (P.42-43: year 1957) about the reducing line speed toward inner radius of record: " **This causes a progressive attenuation of treble from the outside to the inside of a record. To compensate for this some recording companies use a progressively increasing treble pre-emphasis as the stylus moves across the record. This is known as "*radius correction*"".** In my estimation many recording companies since SP era had applied radius correction plus standard recording curve (RIAA/IEC/BS etc) during recording process in order to make good sound balance across the records. **When old records have been recorded in such way (pre-compensated suitably for reproduction by standard spherical tip), then advanced line contact stylus with much reduced tracing loss would reproduce unbalance (emphasis on high frequency band) at inner groove radii of records.** It is quite questionable whether modern records have been recorded or designed suitably for any special styli or not. *As of today there is no well-established standard except for spherical styli.* BTW: Radius correction has both desired and undesired effects on sound: frequency response across the record may be improving while the tracing distortion is increasing by additional emphasis on treble. This dilemma could be solved by tracing compensator (pre-deformed signal recording) in early 1970s? It remains unclear since many recording companies stopped mentioning specific solution after late 1970s. In vinyl record one solution of a problem is apt to produce another kind of problem like a whack-a-mole game. I find most significant passage in NAB(1964) as follows: "In disc recording, it is the generally accepted practice to evaluate sound quality and musical balance of a disc on a reproducer which has a specified response (frequency characteristic)". This point is often ignored by many audiophiles who discuss sound quality with their favourite equipment used. I feel enough with their reviews. Phew!





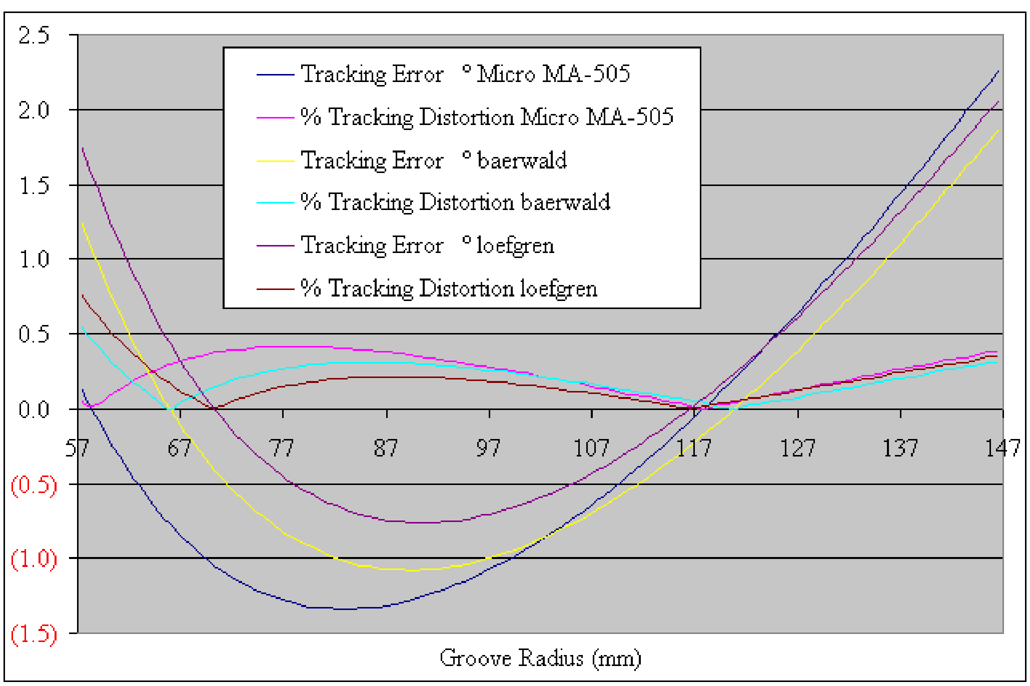
Due to different angles between VMA (effective vertical modulation angle) at recording and VTA (vertical tracking angle) at reproduction

C. Vertical Tracking Distortion: The height adjustment of arm cannot affect this distortion on a large scale since the rate of height change at arm post is very limited: *max±1.3degree by ±5mm at the effective lateral length of arm 220mm* while *nominal* VTA of current cartridge is ranging from 15 to 25 degrees and there is no way to ascertain actual VMA of each record. It is truly complicated about distortion arising from the difference between VMA and VTA. Note that 2nd harmonic distortion % as shown in graph is based on one sinusoidal wave only while there must be another distortion from mixed tones as used in measuring VTA of cartridge by DIN 45542 test record (f1=1850 or 370Hz f2=3150 or 630Hz) etc. *IMO: QUALITY CONTROL of cartridge about VTA&SRA is most important since sound quality cannot be improved afterward by changing VTA of existing cartridges forcibly to comply with VMA: to change VTA drastically is to change SRA at the same time - deviating further from allowable range of SRA between +4 and -8degrees for non-spherical tip.*



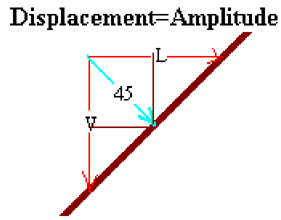
Due to the error of Lateral Angle/Alignment

D. Lateral Tracking Distortion: The distortion rate at larger error angle is similar to that at VTA difference (see above graph). **This 2nd harmonic distortion can be reduced to less than 1% with correct alignment for pivoted arms.** When the deviation from exact alignment is within +/-3mm for overhang (shift on shell) or shift of arm on bedplate, then error angle is within +/-4degree and distortion less than 2% with 9inches arms at signal velocity 5cm/sec. Theoretically 0% for linear tracking arms (nominal error max 0.15degree for most linear trackers using LED+photo sensor+motor to control angle error). The following graph shows comparison of Micro MA-505 (Effective Length 237mm near to "Stevenson type" alignment) and "Baerwald and Loefgren type" alignments applied for the arms of same length when aligned each as designed. **Note on this graph**: in order to make prompt and easy comparison with other graphs of distortion & ratings, signal velocity is set at 5cm/sec instead of usual 10cm/sec.



Theoretical rate of distortions:

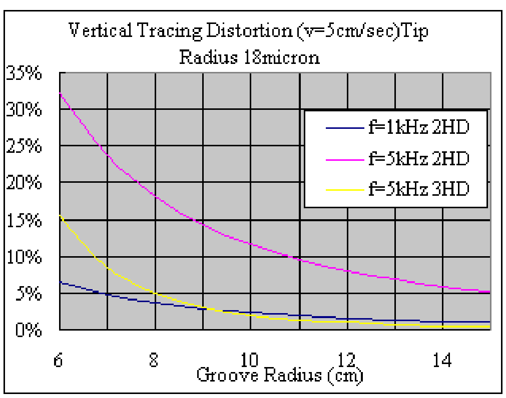
For example: tracing 5kHz <u>velocity of 5cm/sec peak</u> with spherical tip radius 18micron=0.7mil. Velocity 5cm in the following analysis should be understood as <u>vertical modulation velocity for A & C</u> and <u>horizontal/lateral modulation velocity for B & D</u>. But all distortions from A to D will be involved in actual stereophonic groove which has lateral and vertical components. In stereophonic pickup the velocity toward 45 degrees should be counted - hence vertical or lateral modulation velocity 5cm/s can be converted to 3.54cm/s [=5/SQRT(2)] <u>per channel</u> for direction towards 45degrees. Inversely modulation velocity toward 45degrees can be divided into x1/SQRT(2) each for lateral and vertical components. Hence upon measuring distortion actually on test record, we must be careful about the kind of groove (<u>vertical/horizontal/45</u>) and its velocity specified in <u>cm/s peak or rms</u>.

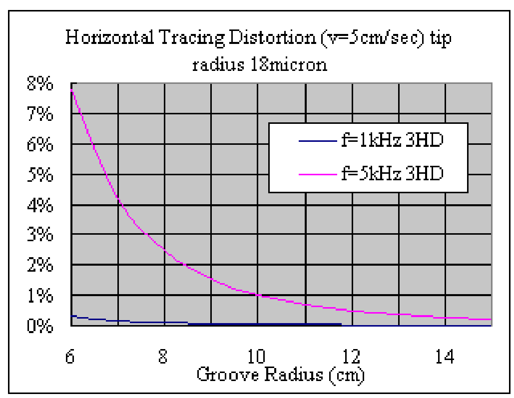


At inner groove radius 6cm
A. Vertical tracing distortion/VTD:2nd harmonic distortion rating 32%, 3rd harmonic distortion 16%
B. Horizontal=Lateral tracing distortion/LTD: Mainly 3rd harmonic distortion 8%
C. Vertical tracking distortion/VtD: 2nd HD 2.1% with Cartridge VTA 5degree different from VMA, 4.2% in case of 10degree difference
D. Lateral tracking distortion/LtD: Baerwald type alignment usually under 0.3% for groove radii 60-146mm. If you use Stevenson type alignment null point around 60.325mm, then distortion is ignorable toward inmost groove.

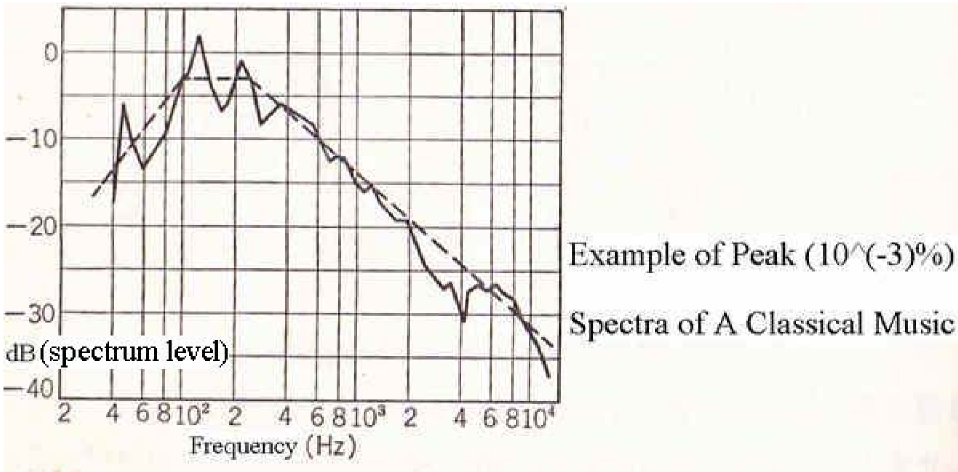
At outer groove radius 14cm
A. VTD: 2nd harmonic distortion rating 6%, 3rd harmonic distortion 0.5%
B. LTD: Mainly 3rd harmonic distortion 0.3%
C. VtD: 2nd HD 0.9% with Cartridge VTA 5degree difference, 1.8% with VTA 10degree difference
D. LtD: Baerwald type alignment 0.3% for groove radii 60-146mm. If you use Stevenson alignment, then distortion reaches around 0.4% at this radius and around radius 8cm.

In short, vertical tracing distortion is bigger than lateral/horizontal tracing distortion because vertical movement is restricted with contact height only while the needle for horizontal direction is restricted by both sides of walls. And this might be the good reason why monophonic sound with lateral modulation is better than stereophonic sound with 45/45 modulation. I find the following text in US Patent 3229048 for RCA Dynagroove: ***"An analysis of tracing distortion shows that lateral cut records are superior to vertical cut records (hill-and-dale). In lateral cut records, the two groove walls, moving in the opposite directions relative to the reproducing stylus center, form a push-pull system which tends to eliminate the even order harmonic and intermodulation components of tracing distortion. In vertical cut records, vertical-lateral stereophonic records, or in 45-45 type stereophonic records the cancellation of even order harmonic and intermodulation distortion does not take place and the tracing distortion problem becomes significant."***





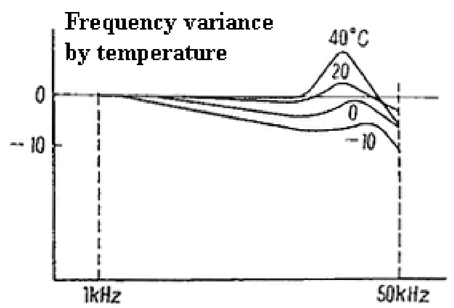
Note on graphs: above input frequencies (f) are fundamental. Hence actual distortion for velocity sensitive cartridge output after phono stage (RIAA equalization) : 2nd harmonic distortion shall be reduced to almost 1/2, 3rd to 1/3 over 5000Hz. These adjustments can be applied for all harmonic distortions though it is complicated further due to pre-emphasis=recording characteristics of RIAA with emphasis around +6dB/Oct at high frequencies. I read that the peak of high frequencies spectra in classical music has level roughly -6dB/Oct as seen in the next graph (a broken line indicates a normalization). In fact the technical background of analog disc recording is based on such data of music proper. Recording curve for LP and suitable recording instruments with due recordable limits have been developed for such music. *IMO: Hence it results in presumably flat/limited recorded velocity over 1kHz by counterbalancing recording emphasis +6dB/Oct with natural decrease around -6dB/Oct toward the highest end - it was lucky technically too. But "new music" or "noises" might have another kind of spectra. Mr. Yamamoto in his book 1971 commented as follows: "The RIAA recording curve was decided originally for monaural LP, hence new recording curve suitable for 4-channel and stereophonic records shall be taken into consideration. Recently new music with much different spectra is emerging so that now it is high time to reconsider RIAA recording characteristics". RIAA curve was standard de facto and not standard de jure. Anyway RIAA standard is good as long as new vinyl disc is not developed anymore and we can enjoy the legacy of LP records in their heyday (mid 1970s on worldwide production scale).* Thus I can understand why many frequency test records with constant/limited velocity over 1kHz are valid in use.



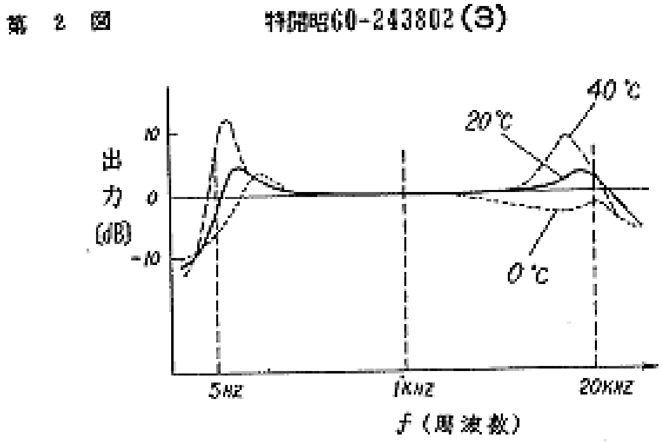
A conclusion: highest distortion for high frequencies arises from VTD at inner groove in particular. Meantime **it is said that the vinyl deformation due to its elasticity reduces such extreme distortions and the real rates of distortions are less than calculated:** Distortion from the elastic deformation of groove wall is rather small in comparison with tracing distortion and it has reverse phase of tracing distortion so that the distortion in effect becomes smaller than the theoretical value of tracing distortion [Shiga: Distortions in Stereo Disc Record 1961]. According to my EXCEL file based on simple geometric simulations, the relative distortion in inner groove radius is rating roughly as **Lateral tracking angle error distortion or Vertical tracking angle error distortion (2nd HD)< Lateral Tracing distortion (3rd HD) < Pinch effect (2nd HD) < Vertical Tracing distortion (2nd HD).**

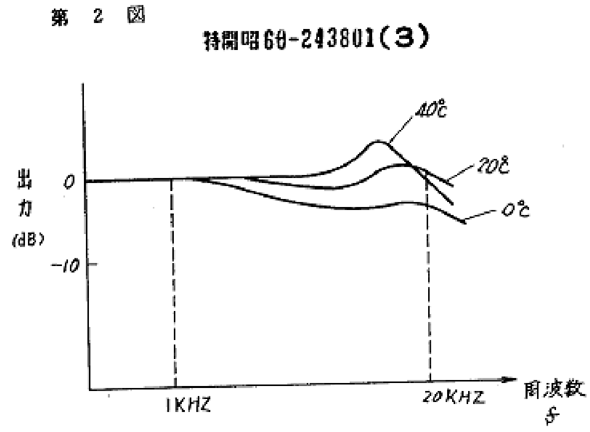
Main problems when simulating the distortions for vinyl reproduction: Above analysis on respective distortions is based on a ball model tracing on sinusoidal groove modulation. And this simulation or calculation is carried out usually on 2 dimensional planes separately. That is: vertical modulation (vertical tracing error from original trajectory of groove modulation)/lateral modulation (lateral tracing error from original trajectory)/pinch effect (additional vertical modulation arising from original lateral modulation)/VTA difference (difference between the vertical movement of cantilever and effective modulated angle of record)/Lateral tracking error because of arc movement of the pivoted arms. Then how is all in all of these distortions? If anyone is skilled in 3D CAD and applied mathematics, please try to make a model of modulated groove/stylus tip/generating system for more realistic simulation. As for me I am not capable of it - I must confess. **Every distortion or deviation has different character having vertical or lateral or 45degrees or non-directional component so that the sum of these distortions in the result is in complex stage (impossible to sum up on one single plane actually).**

Another important factor is the effect of temperature which cannot be ignored. The following figure is taken from JVC book (1979). JVC explains: "*It is well-known that sound quality and tracing condition are affected by temperature. We find two main reasons: 1) the high stiffness of cartridge damper in case of popular cartridges 2) the record stiffness in case of high-class cartridge. Generally the damper of popular cartridges is rather stiff from the first and the temperature affects rubber compliance for tracking ability. In case of high-class cartridge the temperature affects the stiffness of records to change the high frequency resonance and mechanical impedance. This can be measured as follows: 1) measure frequency characteristic after cooling both record and cartridge. 2) cool record only 3) cool cartridge only 4) compare these characteristics with the frequency characteristics under the normal temperature. In case of the high-class cartridges with line-contact stylus for example Shibata tip: the relative stiffness of record is increased from 2 to 4 times in accordance with the wide area of line-contact tip so that the effect of temperature can be expelled out of the hearing range. By this, the variance of temperature can be almost ignorable with normal conditions. However anyway it is impossible to nullify the temperature characteristics of rubbers and plastics. Hence It is recommended to use record player in the environment temperature 20 +/- 10 degrees Celsius (around 69F).*" My note about the **relative** stiffness of record. Usual record stiffness: Poison rate 0.35, Young modulus 3.3 10^9N/m2 average. Shibata in USP37749181-1973 explained the feature of Shibata stylus:"*3) Since the area of contact surface contour between the stylus and the groove walls is relatively large, the result is equivalent to an increase in the stiffness of the record disc, and the resonance frequency of a vibrator becomes a high frequency. Accordingly, frequency characteristics capable of reproducing the recorded sound in an excellent manner are extended to a high frequency band. 4) As is known, the record disc softens when the temperature becomes high, and the above-mentioned resonance frequency fluctuates greatly with temperature. For this reason, in the case of conventional stylus, the resonance frequency is readily affected by the temperature since it is a relatively low frequency. In contrast, in the case of the stylus of this invention, resonance point which fluctuates with temperature is outside of the frequency band used and as a result, is not subject to the effect of temperature variations.*" The damper is mainly made of butyl rubber and its stiffness is controlled by the ratio of sulphur mixed into butyl. JVC (1979)commented on damper: "*As of today, we could not obtain the equivalent equation representing the actual rubber damper of cartridge perfectly.*" Maybe the function of rubber damper is complicated so that simple mechanical simulation based on spring & dash-pot may be valid for a limited range or point only. Various constructions of dampers have been used for cartridges. Some are using double dampers or specially formed like cup. Some dampers are pre-stressed by tension wires to assign the damper to the designed compliance (tension is adjusted by a special device upon assembly) - in such construction, it is said that too tight tension causes over-damping suppressing high frequency while loose tension tends to cause a peak at high frequency. In the course of time, the frequency characteristic of cartridge is changed by time too.



From Japanese patent papers by Technics. These are popular-grade pickups with high frequency resonance lower than 20kHz as JVC pointed out (JVC graph is logarithm extending to 50kHz)? Interestingly left graph shows low frequency resonance together with high frequency resonance.





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