International Institute For Cotton

Technical Research Division

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Research Record No: 159

Crosslinked Interlock And 1x1 Rib
A Mathematical Analysis Of The Test Data

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Classification: Fabrics/Knitted/Properties

Key Words: Interlock, Rib, Relaxed Dimensions, Mercerising, Crosslinking

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Contents

1. Introduction

Research Record No. 129 describes a mathematical analysis of the Project CP78 data which resulted in a number of equations being obtained which can be used to predict the finished "fully relaxed" (*IIC Reference State*) properties of interlock and rib fabrics knowing yarn count, knitted stitch length and also finishing route.

Included in the finishing routes was a crosslinking treatment carried out on the Shirley Institute equipment at a single nominal level of 2½% on weight of fabric of a DHDMEU crosslinking agent. The procedure for the application of the crosslinker is described in *Research Record No. 126* together with a series of bar charts which compare the major fabric properties both with and without crosslinker. Since then, a further series of samples has been produced with a lower amount of crosslinker, namely 1% on weight of fabric. In addition, a similar Control set was produced without crosslinking agent but with identical amounts of softener and stitch lubricants added.

The precise application conditions are as described in *Research Record No. 126* with the exception that the Control set was not re-run down the stenter a second time for curing.

These two sets of treatments have been allocated the following codes for identification during data storage retrieval and display.

JDX1	Crosslinked 1% level
MJDX1	Mercerised, crosslinked 1% level
JDS	Softened control
MJDS	Mercerised, softened control

A similar mathematical analysis has been carried out on the new data generated from this further work and this report presents the findings from this analysis together with graphical illustrations.

2. The Analytical Procedure

The fabric properties considered to be of particular interest especially after applying a chemical crosslinking treatment are the following.

- length shrinkage, %
- courses /cm
- wales /cm
- weight, gsm
- stitch density, S/cm^2
- bursting strength, kPa

From the previous regression analysis described in *Research Record No. 129*, the following mathematical relationships were taken and tested with the new data as well as with some of the existing data. In each case the equations predict the property in the "fully relaxed" state.

Property	Equation Form	Eqn. No.
Courses /cm	$a + b/l + c.\sqrt{avTex}$	1
Wales /cm	$a + b/l + c.\sqrt{avTex}$	2
Weight, gsm	$a + b.Tex/l$	3
Stitch Density, cm^2	$a + b/l^2 + c.avTex$	4
Burst Strength	$a + b/l^2 + c.avTex + d.avSES$	5

Where *l* is the Stitch Length in cm

avTex is the average yarn Tex

avSES is the average yarn single-end strength

a, b, c, d are constants (regression coefficients)

Since shrinkage is influenced not only by the change in the fully relaxed courses and wales but also by the dimensions at which the fabric is finished, the actual values of shrinkage have to be calculated from the unwashed (finished) and the fully relaxed courses and wales.

For each property in turn the regression coefficients and the correlation coefficients were obtained not only for the 1% crosslinked level and its control but also for the following processing routes.

JD, MJD, JDH, MJDH, JDX2, MJDX2

This was done for two reasons.

1. Since the original analysis was carried out, the way in which certain property derivations are calculated has been slightly altered. This means that the regression coefficients obtained are very slightly different from those given in *Research Record No. 129*.
2. It is of interest to compare the un-crosslinked control fabrics (stenter softened) with the original jet dyed and jet dyed, softened and mechanically compacted fabrics (i.e. JD, JDH, MJD, MJDH).

3. Presentation Of Results

Tables giving the regression coefficients, and graphs showing the actual data points as well as the regression curves, have been prepared and these are presented in the Appendix as follows.

Property	Tables		Figures	
	Interlock	Rib	Interlock	Rib
Courses /cm	1	2	1-6	7-12
Wales /cm	3	4	13-18	19-24
Weight, gsm	5	6	25-30	31-36
Burst Strength	7	8	37-42	43-48
Stitch Density	9	10	49-54	55-60
Length Shrinkage (measured)	~	~	61-66	67-62

4. Discussion Of Results

4.1. Relaxed courses /cm

Interlock (*Figures 1-6)*

These graphs show very clearly the effect which a crosslinking treatment has on the fully relaxed course spacings. The 1% crosslinker level (JDX1 & MJDX1) appears to be giving relaxed courses approximately mid-way between the controls and the 2.5% crosslinker level (JDX2 & MJDX2). The open-width finished controls (JDS & MJDS) are surprisingly slightly different from the tubular finished controls (JD, MJD, JDH, MJDH where shown). This is particularly noticeable with the mercerised fabrics.

1x1 Rib (*Figures 7-12)*

These graphs show a similar effect for the 1x1 rib fabrics except that:

a) the relaxed courses in the case of the mercerised fabrics are quite close to the controls;

b) the open-width controls are very similar to the tubular finished controls for both the mercerised and unmercerised fabrics.

4.2. Relaxed wales /cm

Interlock (*Figures 13-18)*

Rather surprisingly these curves show that a crosslinking treatment results in a slight increase in the relaxed wales. This means that for a given width shrinkage, a crosslinked fabric would have to be finished slightly narrower or, conversely, if finished to the same width, would result in a slightly higher width shrinkage figure.

1x1 Rib (*Figures 19-24*)

There is a suggestion that the same would apply to unmercerised 1x1 rib fabrics although to a lesser degree. The mercerised fabrics however all behave very similarly.

4.3. Relaxed weight

Interlock (*Figures 25-30*)

Predictably, the 1% crosslinker treatment is giving fabrics with relaxed weights almost mid-way between the control fabrics and the 2.5% crosslinked fabrics. This applies to the mercerised as well as the unmercerised fabrics.

1x1 Rib (*Figures 31-56*)

The rib fabrics show a slightly different behaviour than the interlock fabrics. The relaxed weight of the 1% crosslinked samples is very near to that of the controls. In fact, with the mercerised fabrics it is arguably impossible to separate them. The 2.5% crosslinked samples however show considerable differences resulting in relaxed fabrics with much lower weights.

4.4. Relaxed bursting strength

Interlock (*Figures 37-42*)

Again, perhaps predictably, the burst strength figures of a 1% unmercerised crosslinked fabric are approximately mid-way between the controls and the 2.5% crosslinked fabric. With the mercerised fabrics, however, there is a tendency for the 1% crosslinked fabrics to have burst strengths approaching those of the controls.

1x1 Rib (*Figures 43-48*)

As for interlock.

4.5. Relaxed stitch density

Interlock (*Figures 49-54*)

Again, with the unmercerised fabrics the 1% crosslinking treatment has given relaxed stitch densities, mid-way between the controls and the 2.5% crosslinked fabrics. With the mercerised fabrics, the 1% crosslinked fabrics and the open-width controls are very similar and have given stitch densities falling between the tubular finished controls and the 2.5% crosslinked fabrics.

1x1 Rib (*Figures 55-60*)

With the rib fabrics the curves for the various treatments are more closely packed together than with the interlock fabrics and, particularly with the mercerised fabrics, it is difficult to separate the 1% crosslinked fabrics from the controls.

4.6. Length Shrinkage

Interlock (*Figures 61-66*)

Shrinkage is determined not only by the fully relaxed structure but the degree to which this structure can be approached by mechanical methods during the finishing operation. With the unmercerised interlock fabrics it has been possible to approach this structure better by tubular finishing methods than by an open-width method, thus resulting in lower length shrinkage figures. The converse is the case with the mercerised fabrics.

Crosslinking clearly has the effect of reducing length shrinkage and the difference between the two crosslinker levels is more apparent with the unmercerised than the mercerised fabrics.

1x1 Rib (*Figures 67-72*)

The tubular and open-width finishing routes show similar length shrinkage results on both the unmercerised and mercerised fabrics. The effect of applying crosslinking agent is again very clear with the 1% level giving residual length shrinkage values between the controls and the 2.5% crosslinker level.

5. Conclusions

It is very clear from the results presented in this report that the application of a crosslinking agent can produce in some cases considerable alteration to the fully relaxed properties of knitted 1x1 rib and interlock fabrics.

The degree to which a particular property is changed by crosslinking can be influenced by whether or not the fabric has been pre-mercerised. The extent to which a particular property is changed by crosslinking can be predicted, using the *Equations 1-5* given in the text, together with the coefficients obtained as a result of this latest analysis. However, this can only be done where the level of crosslinking agent corresponds with those on which the analysis was carried out, i.e. 1% & 2.5% levels.

To be used in the STARFISH model it will be necessary to produce equations in which the level of crosslinking agent is one of the independent variables.

With only two levels of crosslinking carried out so far this is not possible and, therefore, two other application levels should be carried out, one of which should be intermediate. Suggested levels for a further two treatments are 1¾% and 3¼% crosslinker based on fabric dry weight.

The major surprise of this work, as far as the author is concerned, is the effect of crosslinking on width stability. It had been assumed that crosslinking would enable fabrics to be finished wider without a corresponding increase in width shrinkage but the evidence so far shows this not to be the case.

Table 1: **Interlock** **Relaxed Courses /cm** $y = a + b/l + c.\sqrt{avTex}$

ROUTE	a	b	c	r^2
JD	-3.5492	5.6407	0.5093	0.9134
JDS	-7.6712	5.9478	1.2531	0.9492
JDH	-5.6078	5.8293	0.9176	0.9882
JDX1	-10.7313	6.3928	1.4229	0.9447
JDX2	-15.9569	6.4323	2.3612	0.9741
MJD	-4.0904	4.8419	0.7888	0.9593
MJDS	-7.2772	5.0959	1.1764	0.9801
MJDH	-8.9480	5.2270	1.6488	0.9594
MJDX1	-9.7433	5.3197	1.4125	0.9896
MJDX2	-10.4175	5.0690	1.5870	0.9906

Table 2: **1x1 Rib** **Relaxed Courses /cm** $y = a + b/l + c.\sqrt{avTex}$

ROUTE	a	b	c	r^2
JD	-6.1717	5.4206	1.0509	0.9786
JDS	-13.6679	6.6677	1.7915	0.9207
JDH	-6.4361	5.8265	0.8113	0.9912
JDX1	-9.0063	6.2029	0.8483	0.9817
JDX2	-15.1588	6.6755	1.6359	0.9876
MJD	-6.4754	4.7121	1.2995	0.9814
MJDS	-9.0398	5.4079	1.3239	0.9853
MJDH	-7.8660	5.3470	1.1733	0.9855
MJDX1	-12.1961	5.6458	1.7910	0.9878
MJDX2	-12.9781	5.6975	1.5944	0.9884

Table 3: **Interlock** **Relaxed Wales /cm** $y = a + b/l + c.\sqrt{avTex}$

ROUTE	a	b	c	r^2
JD	11.9287	2.6948	-1.5174	0.9277
JDS	12.9855	2.9959	-2.0017	0.7935
JDH	15.1384	2.0530	-1.7819	0.9671
JDX1	13.3130	3.2185	-2.1502	0.9592
JDX2	17.4021	2.9459	-2.9057	0.9118
MJD	13.2070	3.7204	-2.0359	0.9525
MJDS	16.2738	3.4169	-2.5420	0.9507
MJDH	16.3844	3.4930	-2.6370	0.9207
MJDX1	17.3751	3.4903	-2.7292	0.9525
MJDX2	15.7390	3.4594	-2.3357	0.9160

Table 4: **1x1 Rib** **Relaxed Wales /cm** $y = a + b/l + c.\sqrt{avTex}$

ROUTE	a	b	c	r^2
JD	2.4521	2.4227	-0.0542	0.9670
JDS	2.8308	2.2300	0.0412	0.9603
JDH	3.1678	2.4155	-0.2015	0.9570
JDX1	5.8845	1.9845	-0.4361	0.9372
JDX2	7.5667	1.7346	-0.6060	0.9385
MJD	7.5155	2.6116	-0.9590	0.9741
MJDS	8.2560	2.6908	-1.1821	0.9542
MJDH	8.2784	2.4880	-1.0314	0.9562
MJDX1	7.4502	2.6224	-0.9337	0.9669
MJDX2	11.1147	2.1977	-1.3830	0.9499

Table 5: **Interlock** **Relaxed Weight** ***y = a + b.Tex/l***

ROUTE	a	b	c	r^2
JD	33.6342	4.0873		0.9611
JDS	19.1307	4.2570		0.9813
JDH	55.6740	3.5740		0.9755
JDX1	17.6816	3.9038		0.9727
JDX2	-20.5055	4.0468		0.9692
MJD	28.9325	4.2765		0.9586
MJDS	19.6162	4.1946		0.9849
MJDH	12.9845	4.5426		0.9554
MJDX1	7.5110	4.1622		0.9873
MJDX2	9.4247	3.8565		0.9228

Table 6: **1x1 Rib** **Relaxed Weight** ***y = a + b.Tex/l***

ROUTE	a	b	c	r^2
JD	-20.6469	3.3562		0.9848
JDS	-21.0185	3.3336		0.9843
JDH	-17.9697	3.2629		0.9920
JDX1	-4.7707	2.9031		0.9759
JDX2	-25.2057	2.8047		0.9507
MJD	-7.5608	3.2408		0.9815
MJDS	-2.2848	3.1611		0.9936
MJDH	2.0065	3.1007		0.9922
MJDX1	-14.0340	3.3167		0.9898
MJDX2	-18.4921	2.7632		0.9537

Table 7: **Interlock** **Relaxed Burst Strength** $y = a + b./l^2 + c.avTex + d.avSES$

ROUTE	a	b	c	d.	r^2
JD	−416.1761	40.7293	24.6442	1.4342	0.9671
JDS	−579.3961	36.0420	132.9332	−7.5644	0.9734
JDH					
JDX1	−472.8922	29.0491	76.6324	−4.1131	0.9068
JDX2	−332.8345	22.0186	21.8599	1.4837	0.9494
MJD	98.1875	46.9527	−87.9993	7.7962	0.9490
MJDS	−356.3690	31.6004	−32.5402	6.6693	0.9088
MJDH	−524.0245	44.6208	18.9080	2.6994	0.9378
MJDX1	−590.6757	28.8416	89.1019	−2.4105	0.9558
MJDX2	−673.5854	25.3612	79.9465	−2.0040	0.9690

Table 8: **1x1 Rib** **Relaxed Burst Strength** $y = a + b./l^2 + c.avTex + d.avSES$

ROUTE	a	b	c	d.	r^2
JD	53.7231	25.1252	−108.1893	10.0482	0.9761
JDS	−325.8282	19.8344	23.9943	0.3571	0.9638
JDH	−247.8621	23.5965	−0.0253	2.1186	0.9575
JDX1	1091.2406	19.2057	−208.4182	18.9454	0.9437
JDX2	−236.6941	14.8618	18.6503	−0.1049	0.9082
MJD	−204.0535	27.2352	−15.3758	3.0330	0.9218
MJDS	−232.5650	18.9895	15.6412	1.0861	0.9706
MJDH	−1828.1211	22.6595	516.2410	−32.6020	0.9962
MJDX1	−239.8396	18.6305	34.5615	−0.3986	0.9766
MJDX2	−38.7791	15.3259	−9.7036	2.8522	0.9498

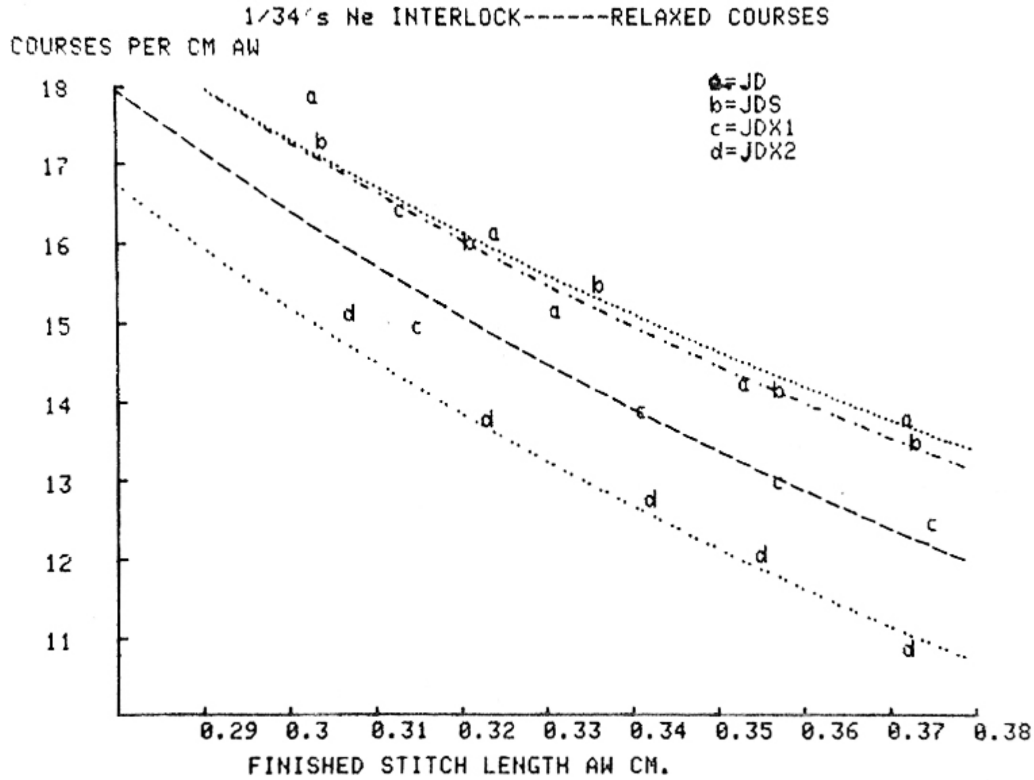
Table 9: **Interlock** **Relaxed Stitch Density** $y = a + b./l^2 + c.avTex$

ROUTE	a	b	c	r^2
JD	65.9756	20.0988	-2.0129	0.9708
JDS	44.7274	21.4175	-1.6066	0.9775
JDH				
JDX1	14.7673	23.0049	-1.1724	0.9588
JDX2	-9.1454	22.1711	-0.2357	0.9773
MJD	62.3570	21.1340	-1.9933	0.9896
MJDS	51.2532	20.7916	-1.8938	0.9890
MJDH	44.7319	21.6119	-1.3575	0.9892
MJDX1	30.4193	21.4564	-1.4011	0.9917
MJDX2	6.2057	20.2697	-0.1113	0.9897

Table 10: **1x1 Rib** **Relaxed Stitch Density** $y = a + b./l^2 + c.avTex$

ROUTE	a	b	c	r^2
JD	-10.9067	14.2343	1.1619	0.9837
JDS	-43.8012	15.7937	2.0524	0.9657
JDH	-5.7814	15.0422	0.4904	0.9933
JDX1	-0.0053	14.3632	0.1624	0.9787
JDX2	-24.7803	14.3315	0.9164	0.9905
MJD	22.5990	14.1140	0.0000	0.9899
MJDS	11.8751	15.4699	-0.2875	0.9958
MJDH	20.3535	15.0998	-0.3271	0.9974
MJDX1	-16.4939	15.8435	0.8040	0.9955
MJDX2	1.6445	14.5060	-0.0856	0.9938

Figure 1



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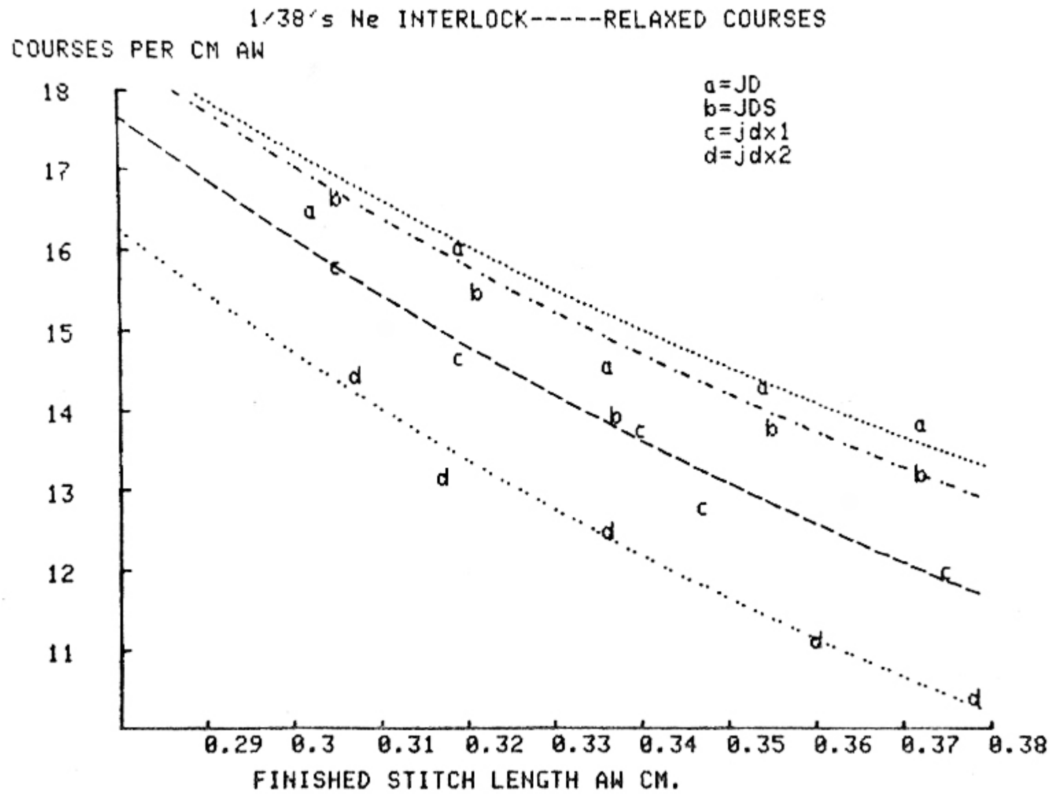

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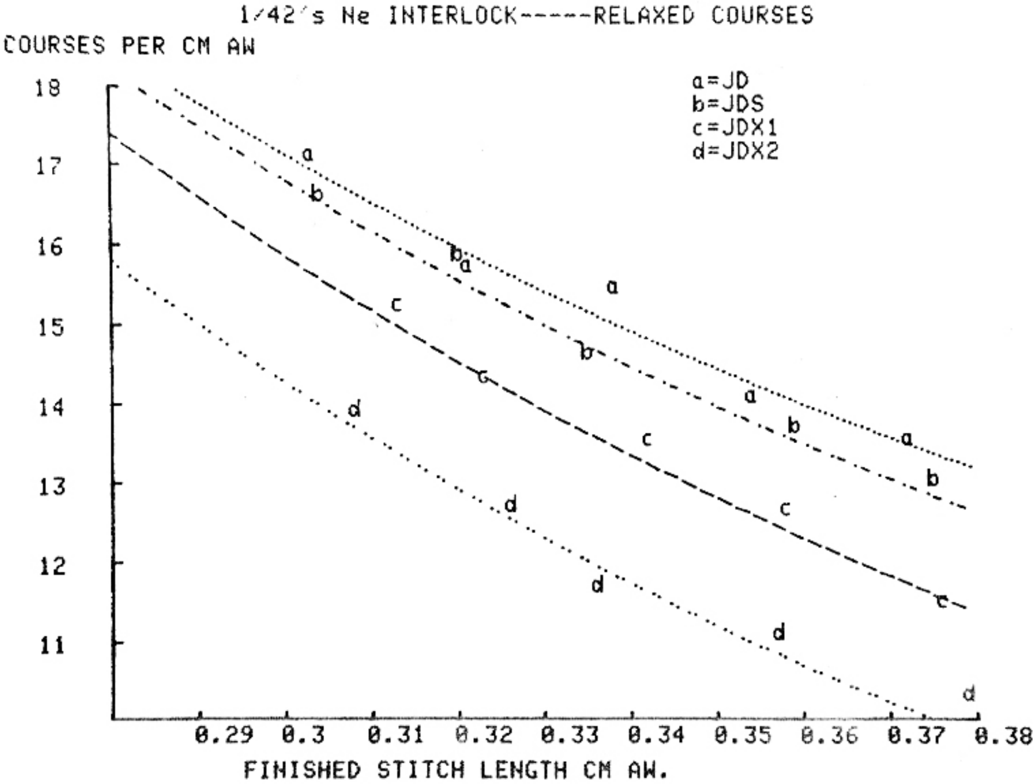

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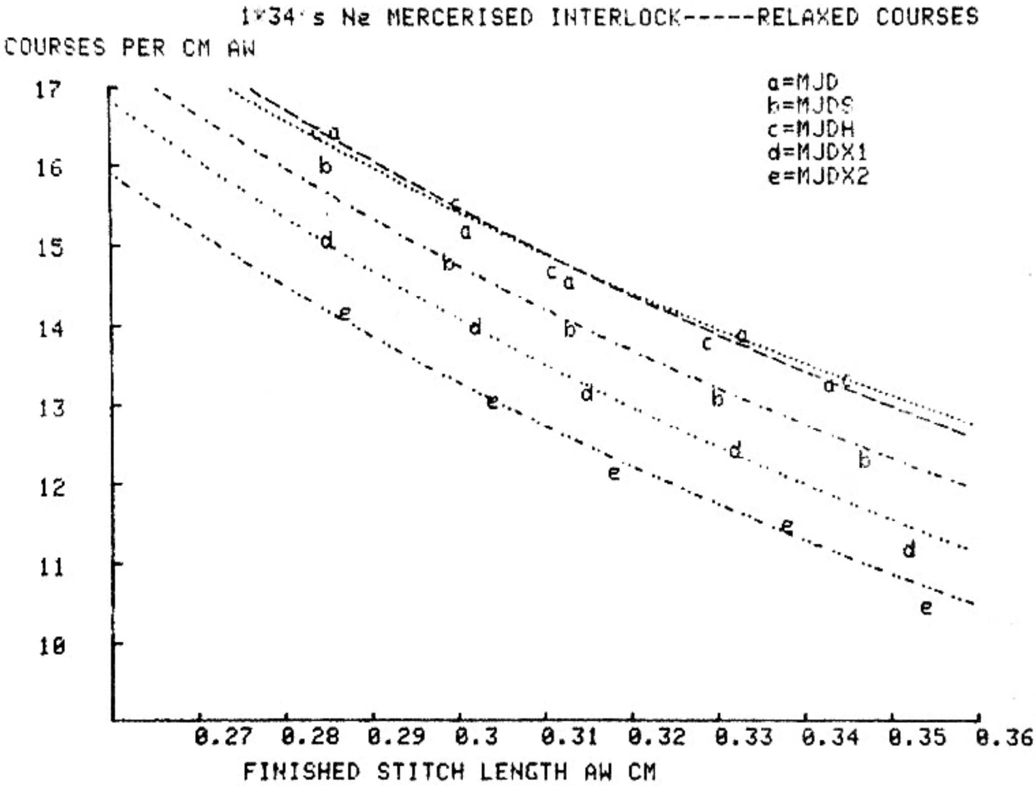

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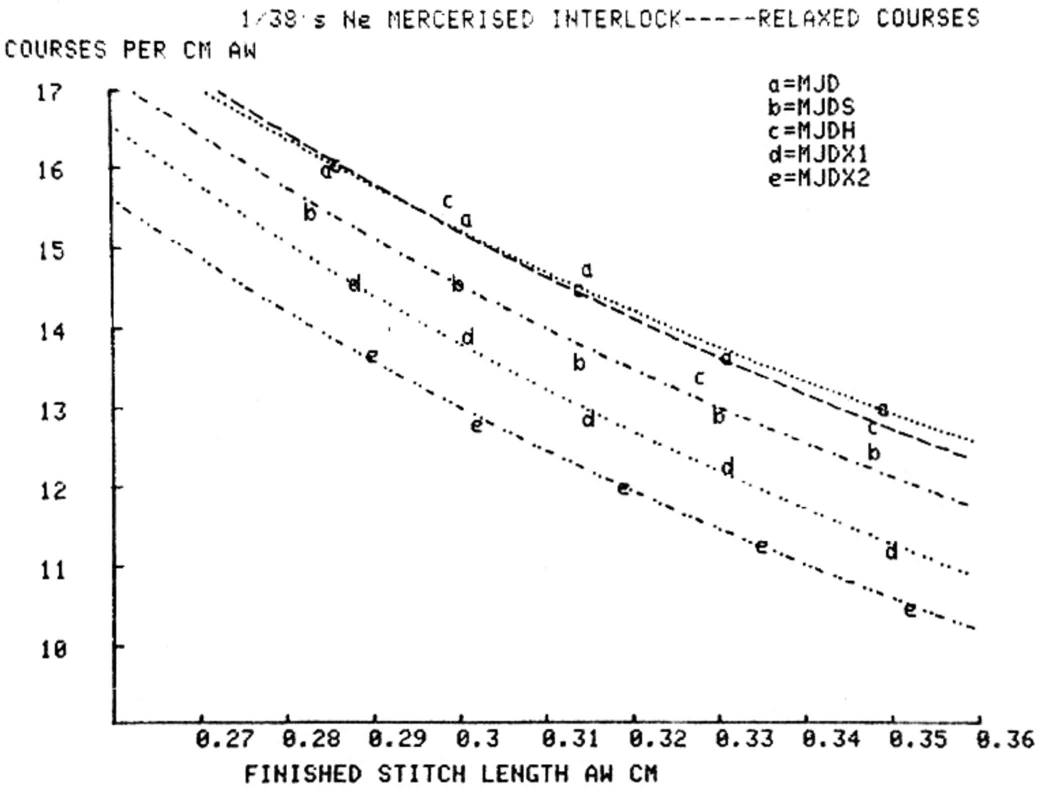

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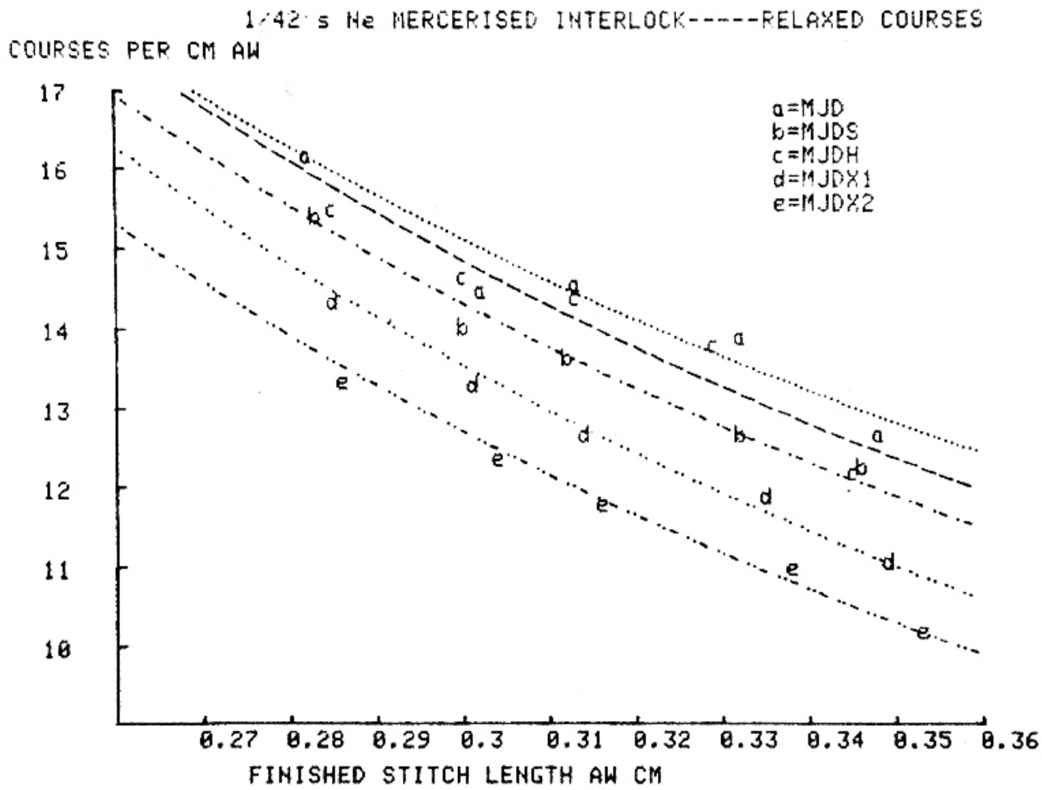

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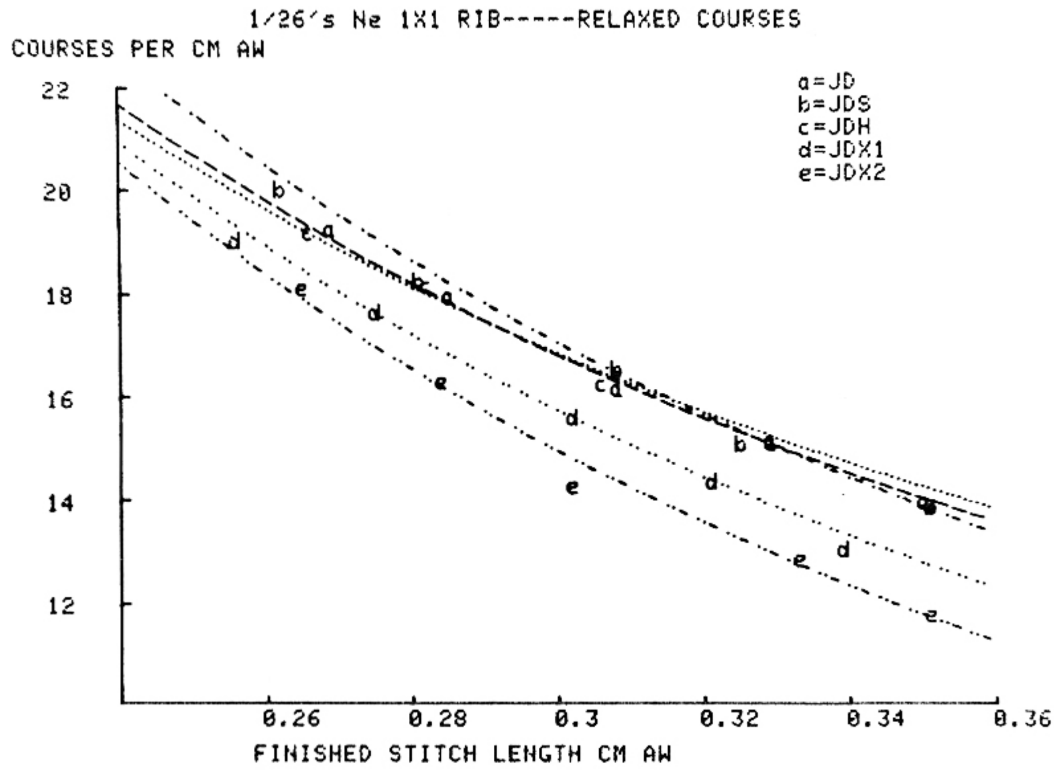

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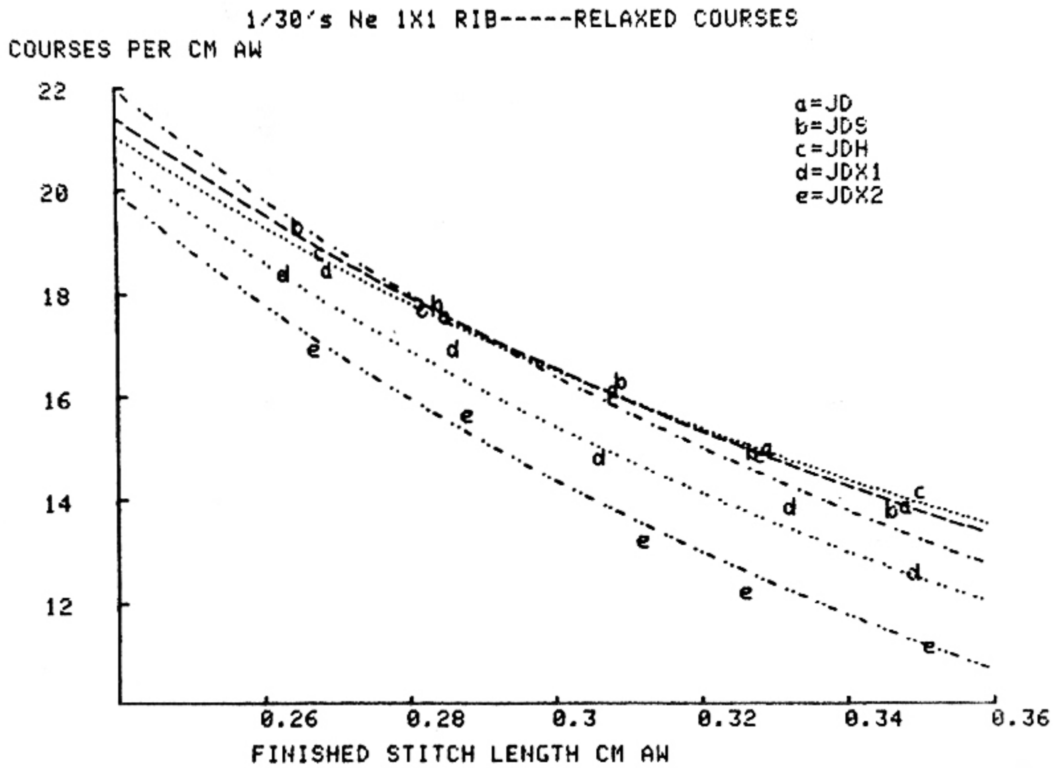

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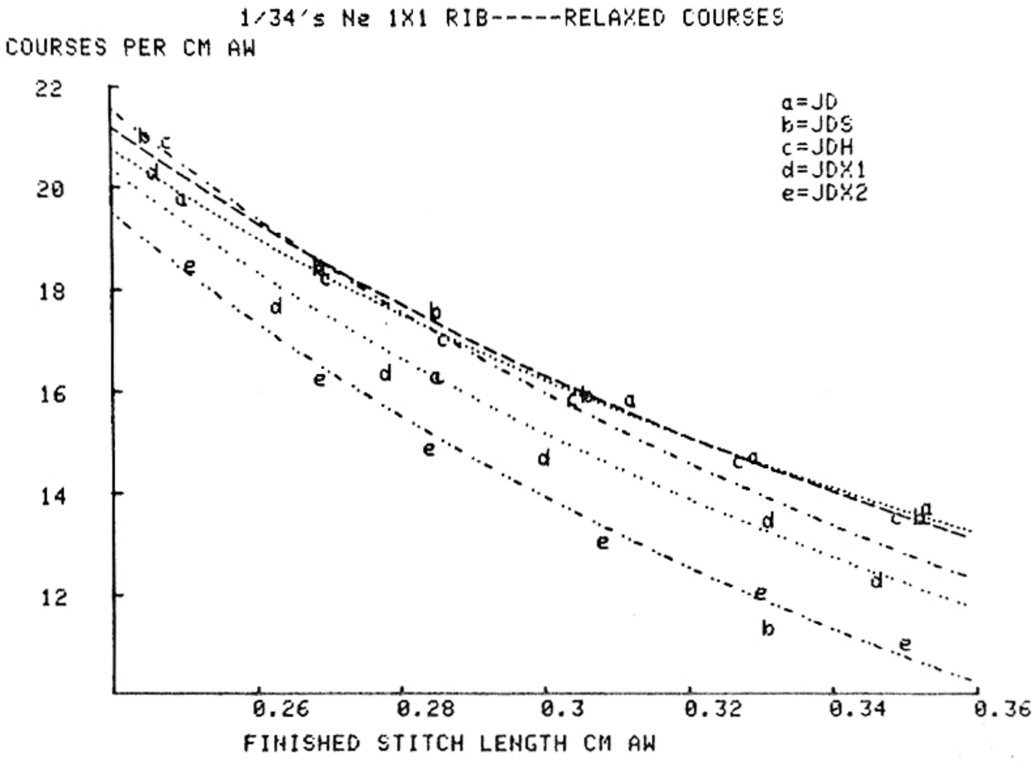

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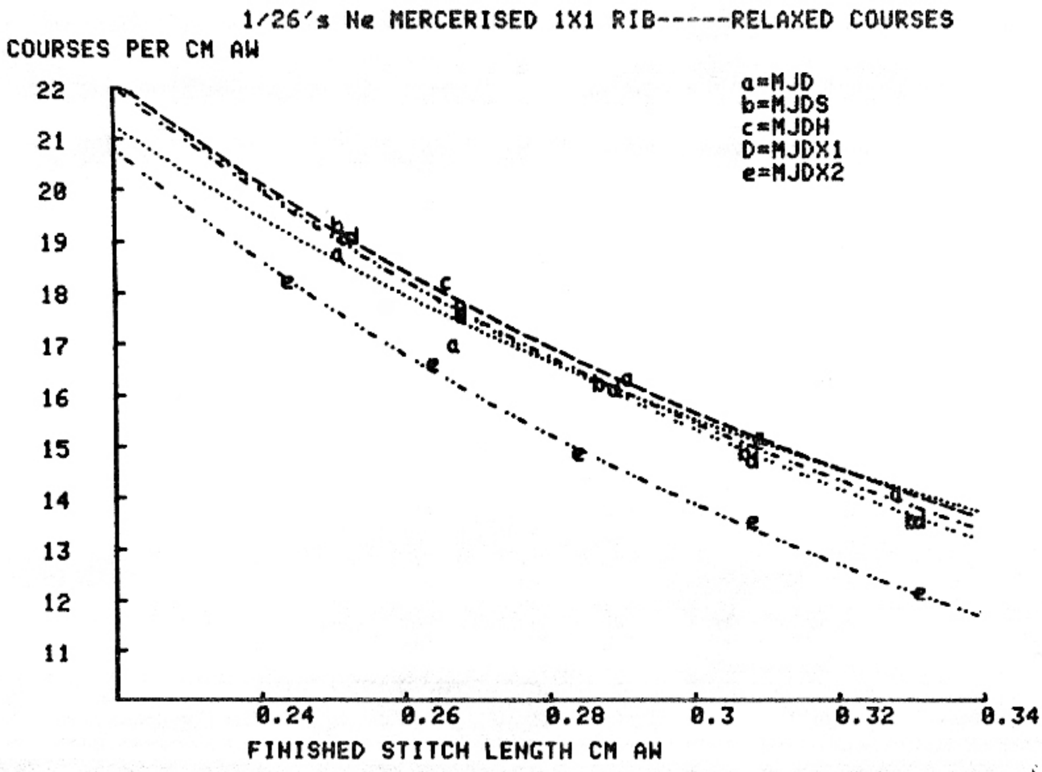

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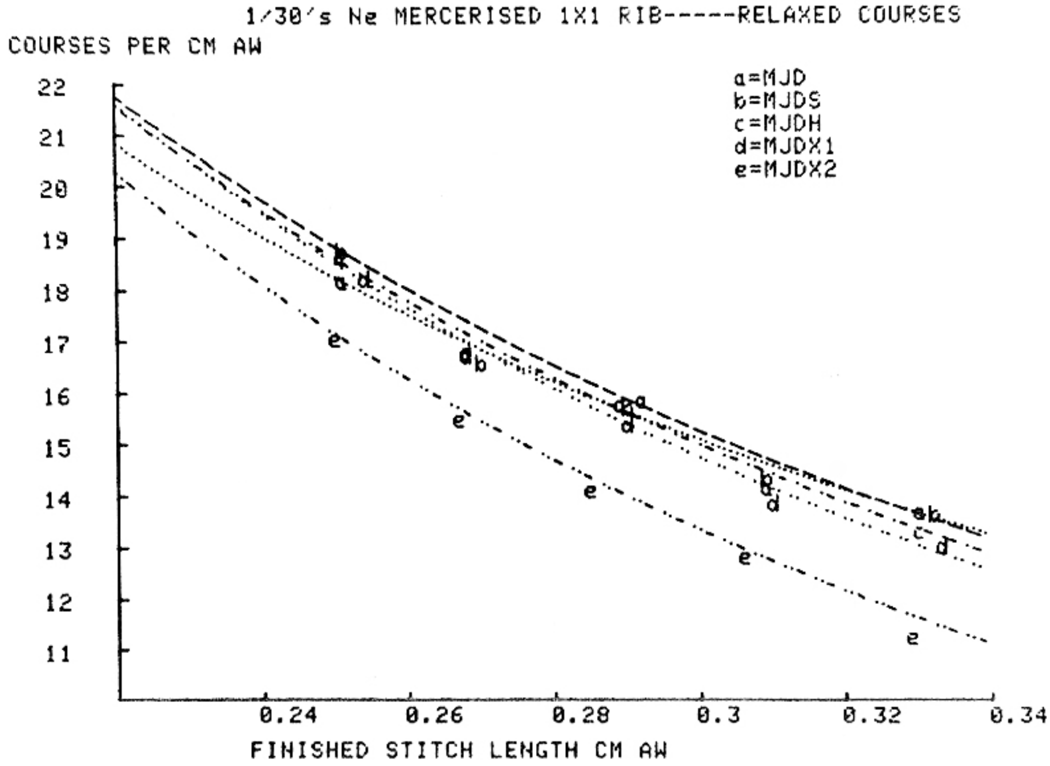

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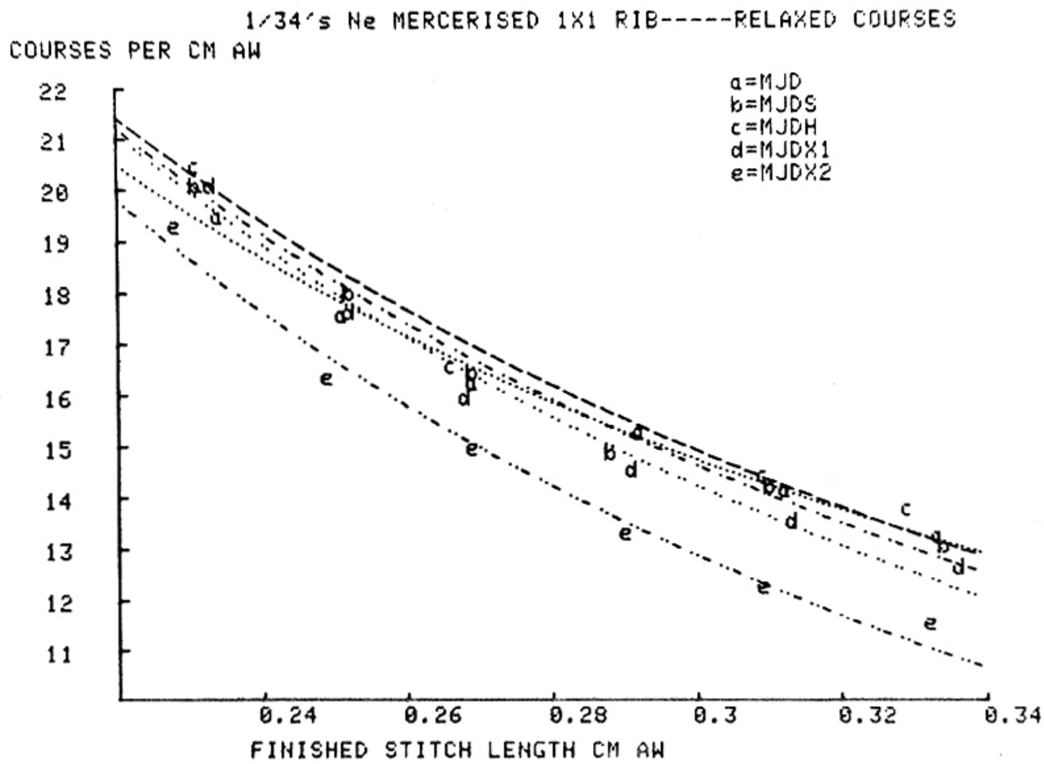

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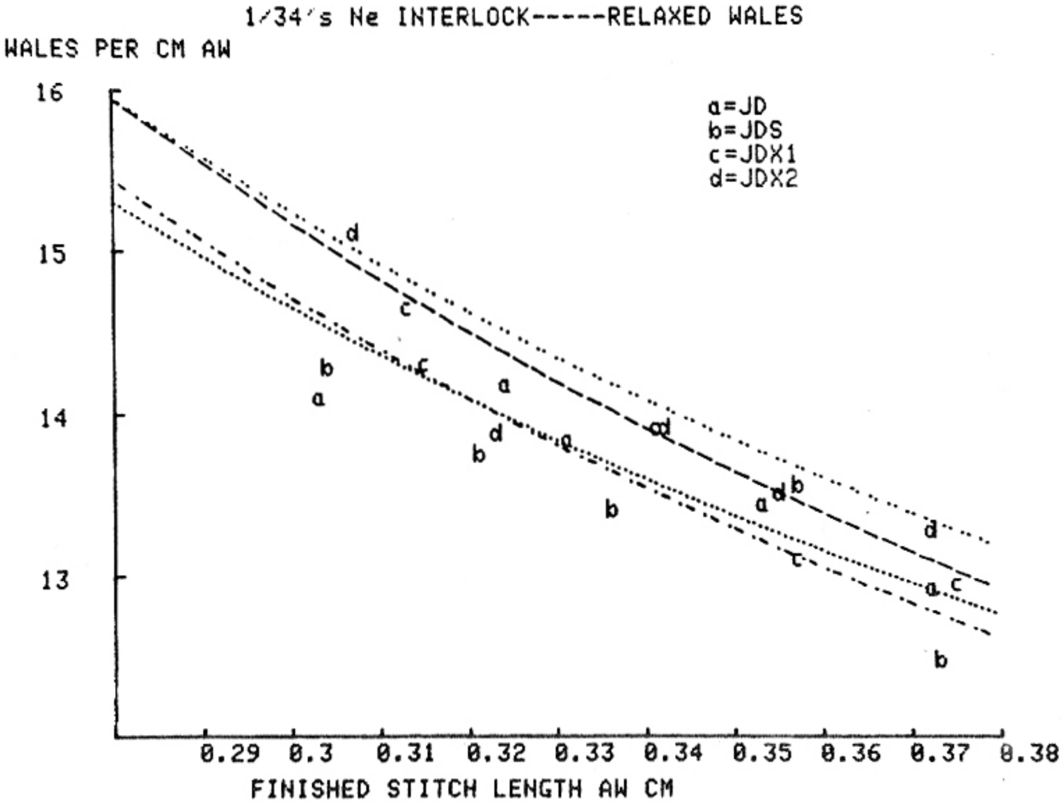

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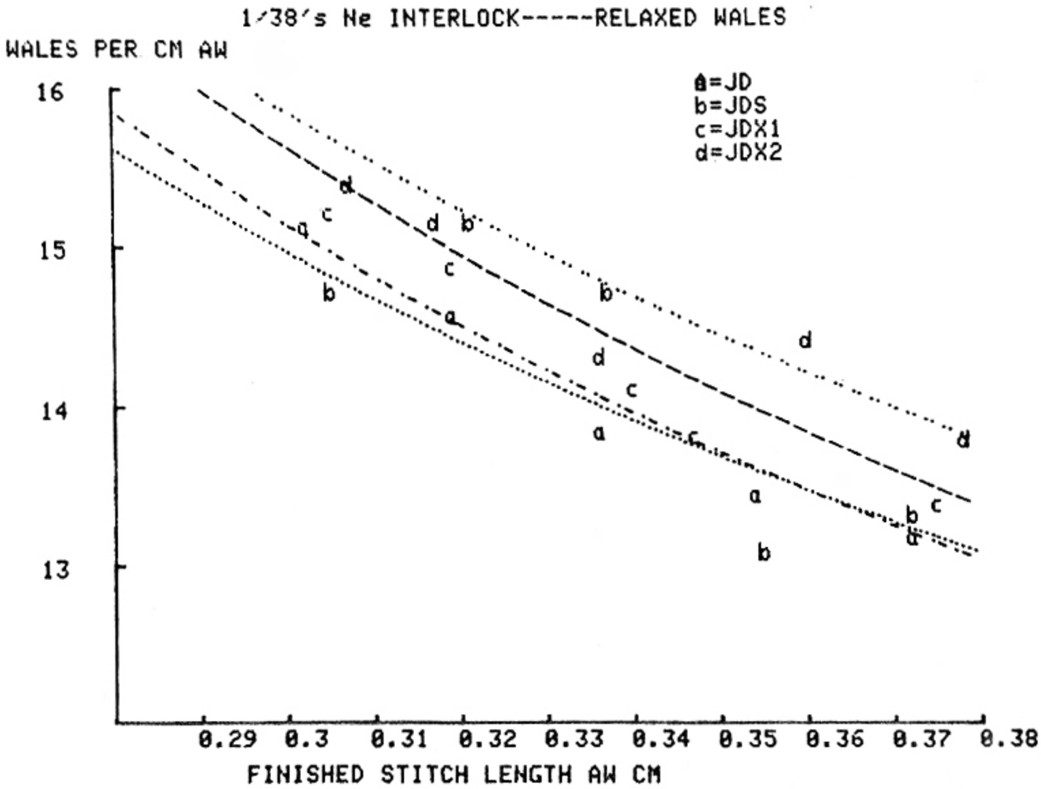

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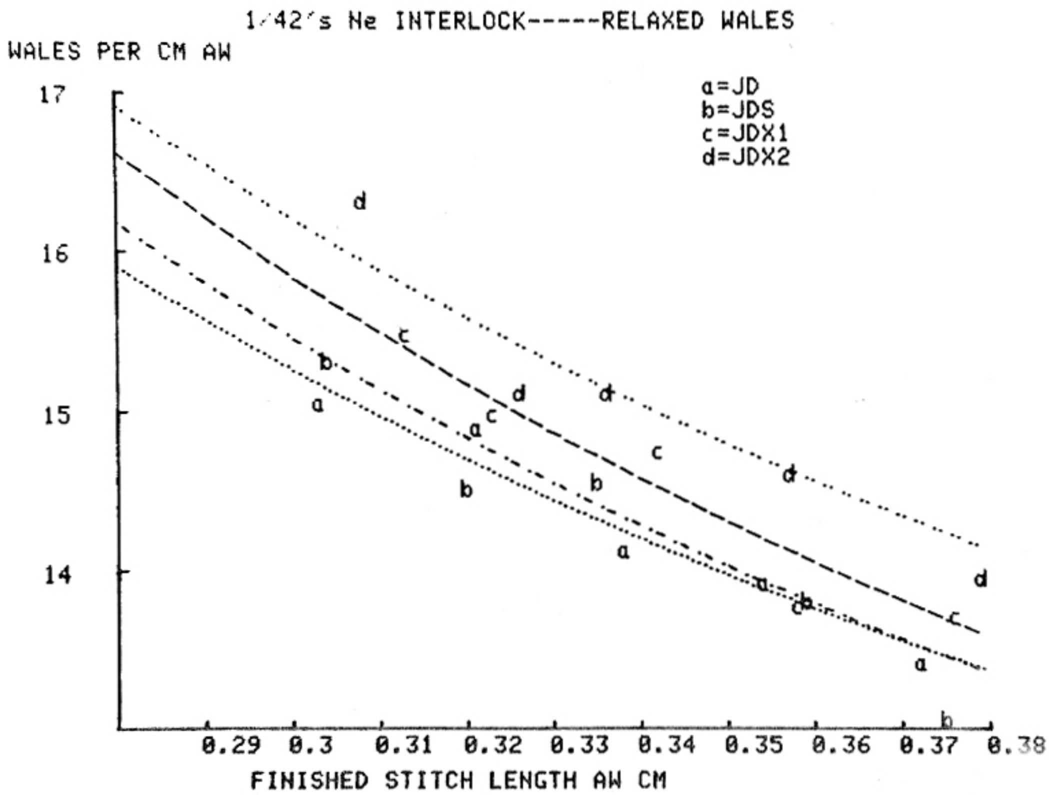

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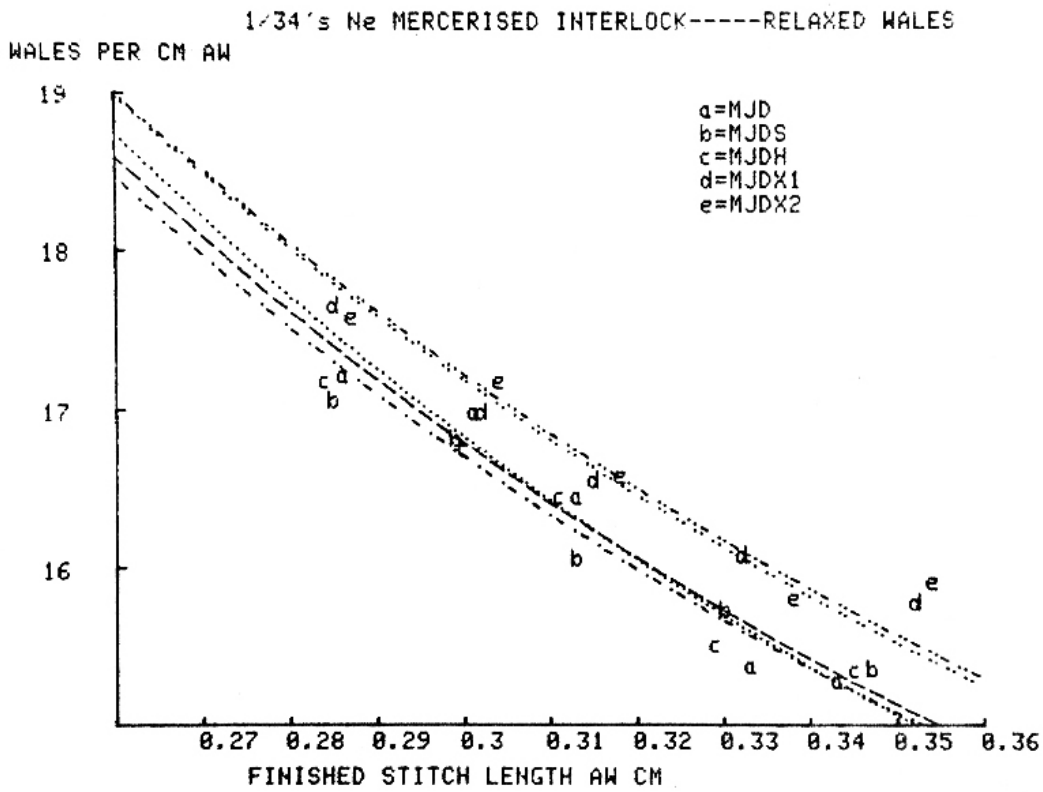

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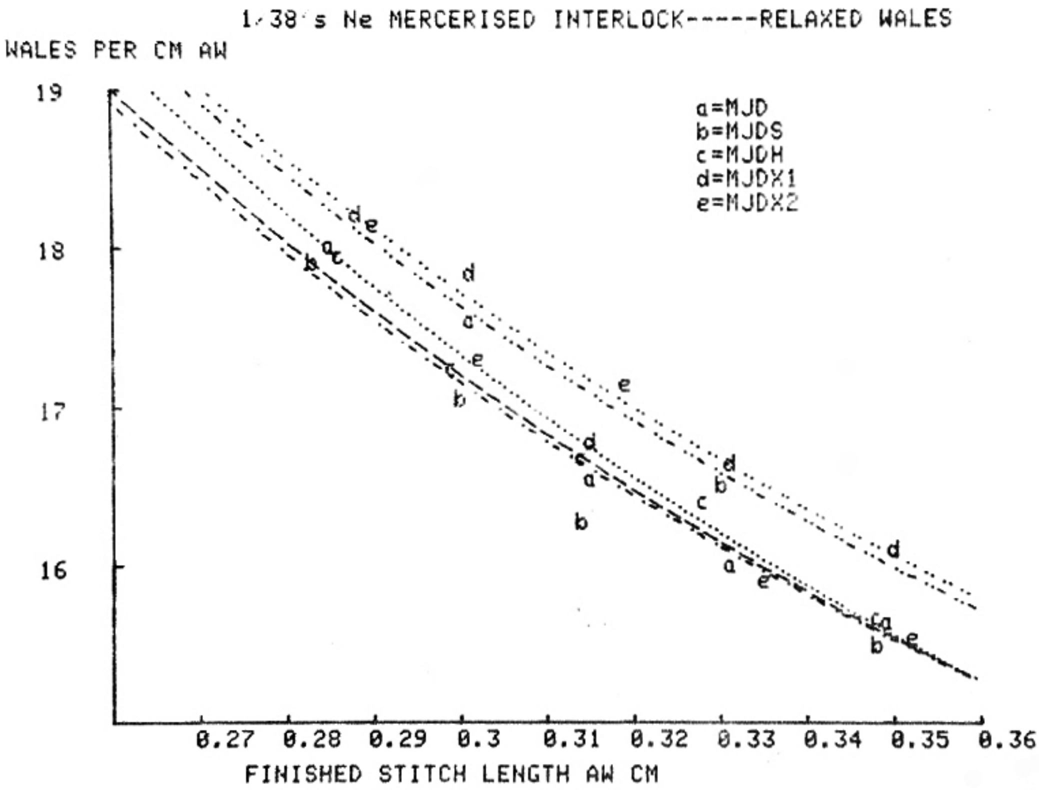

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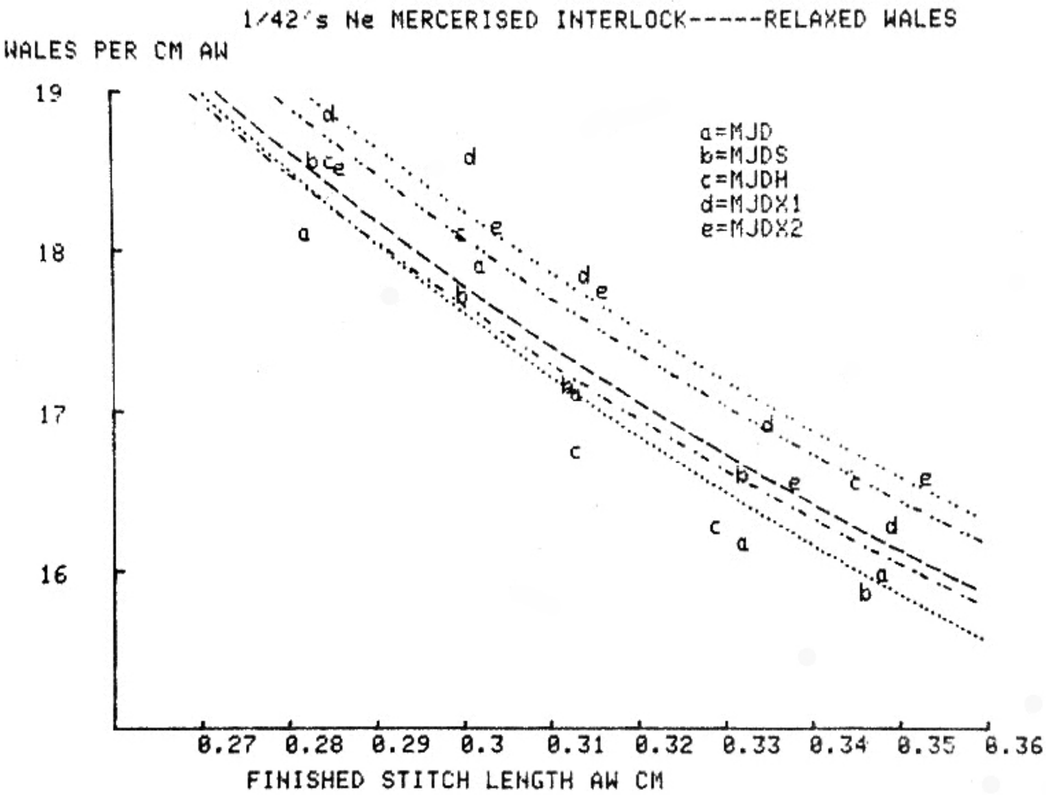

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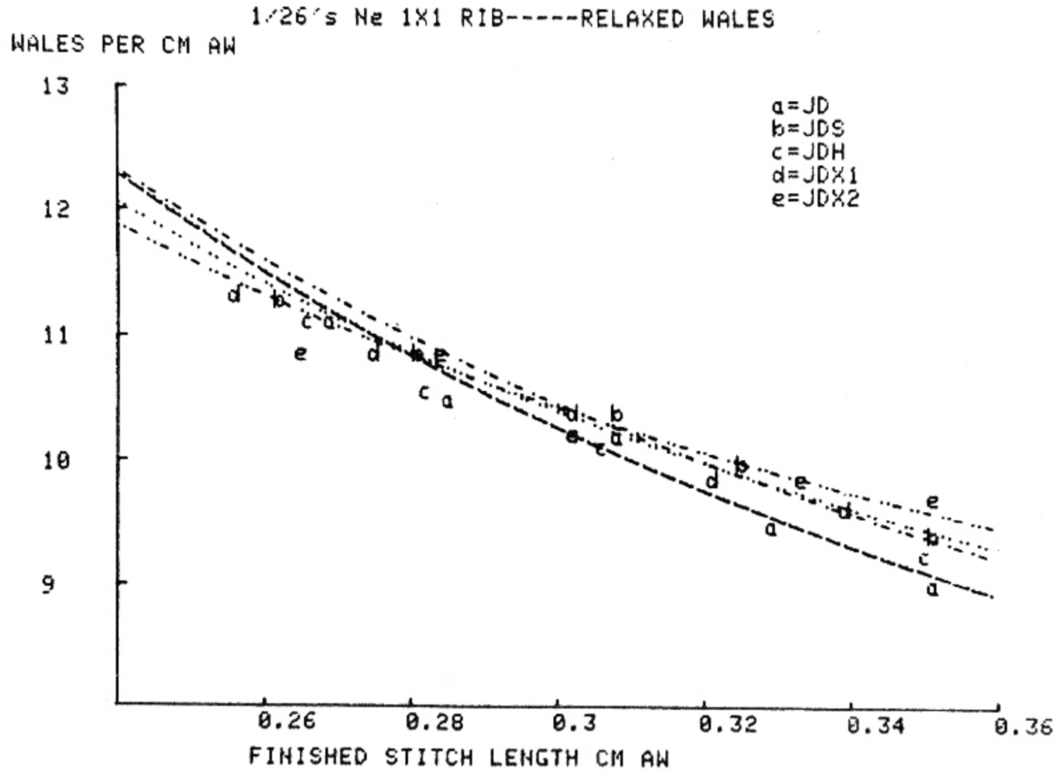

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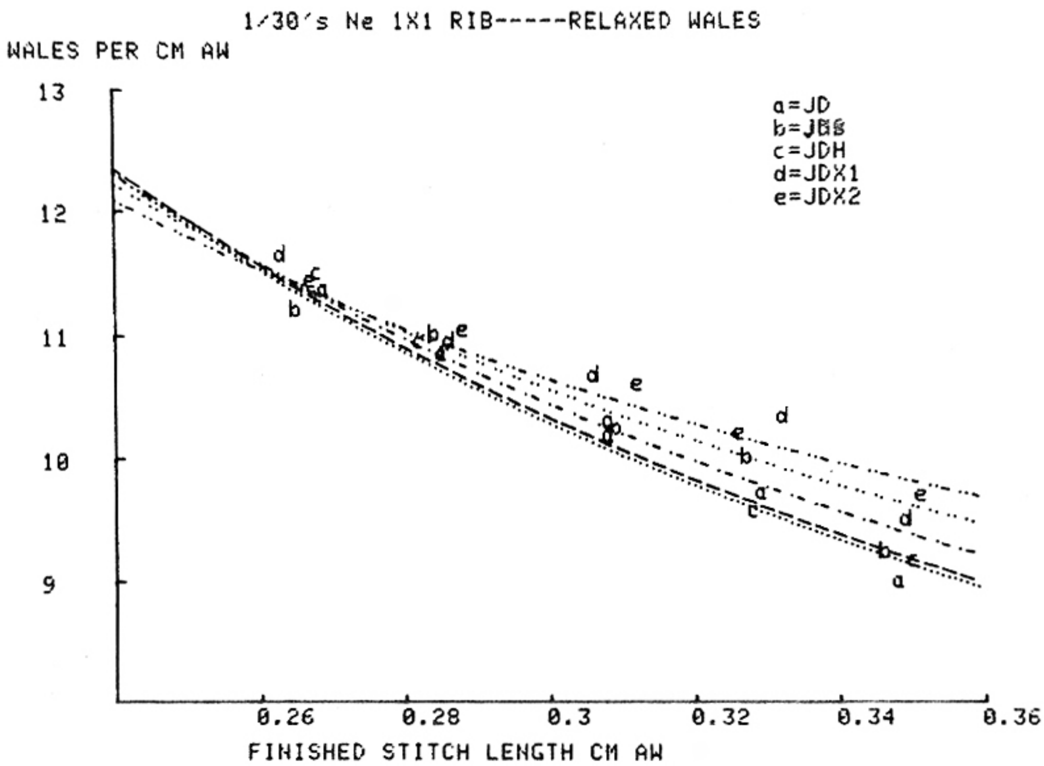

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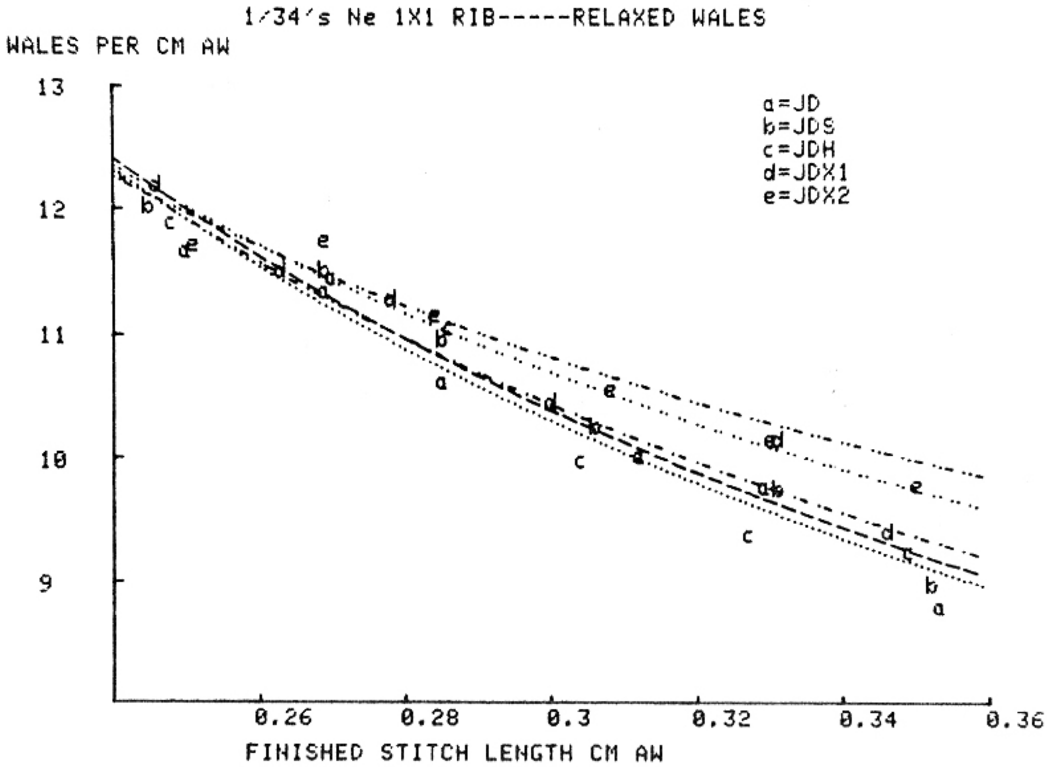

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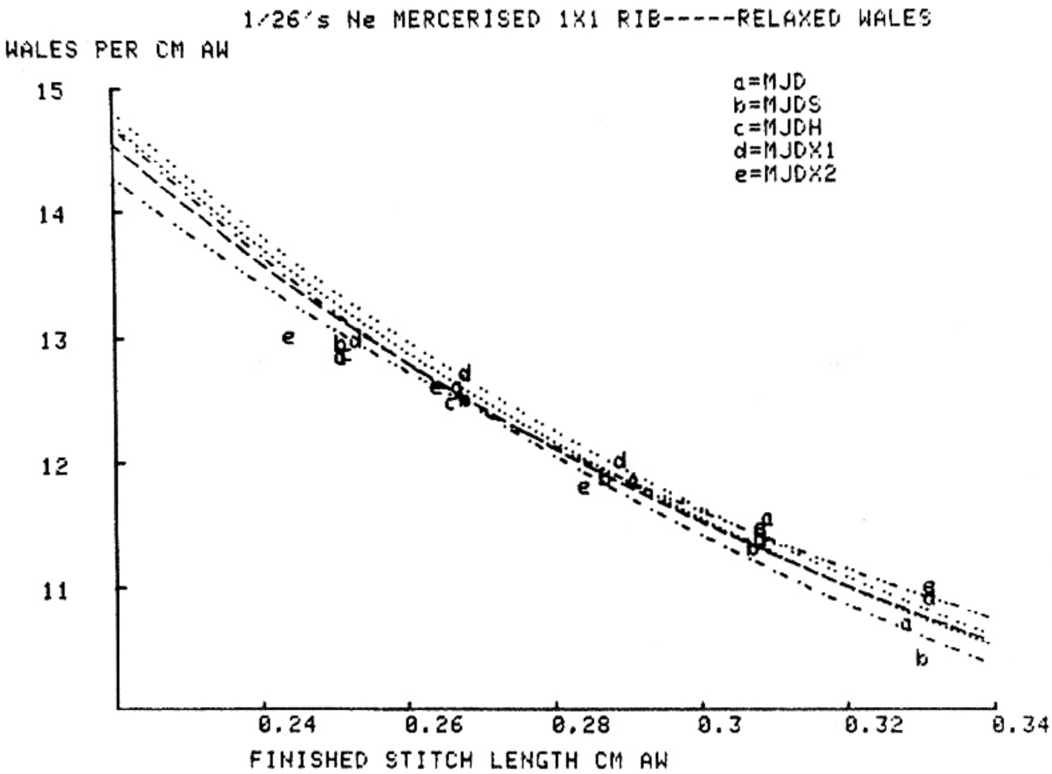

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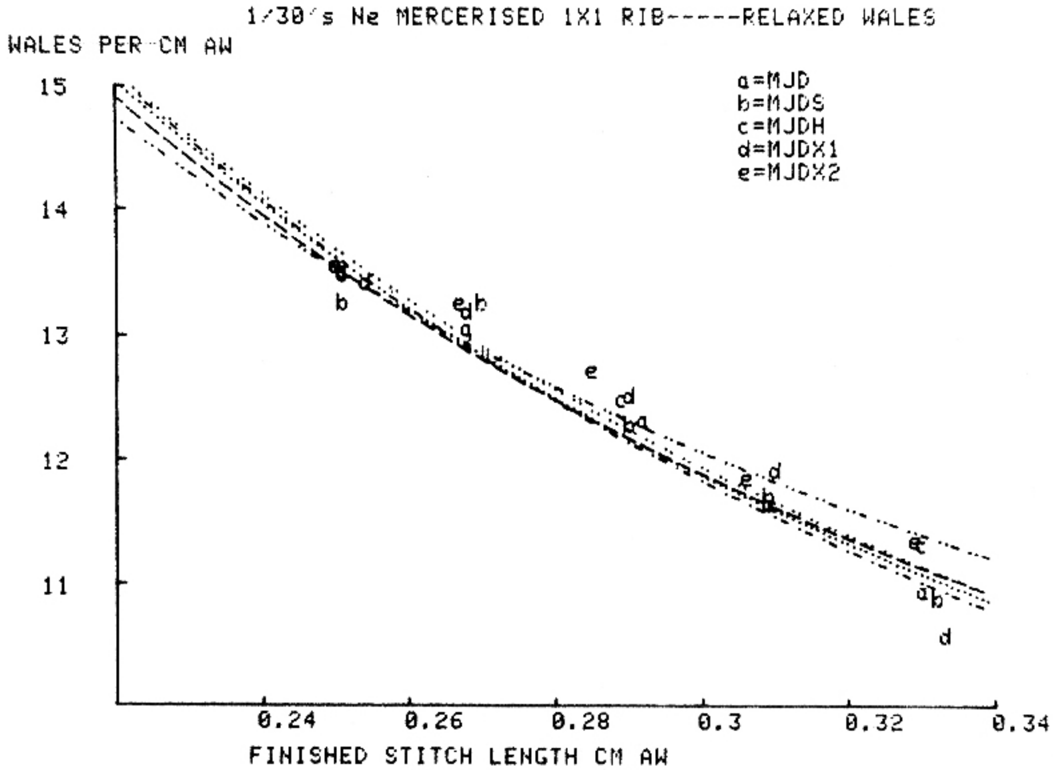

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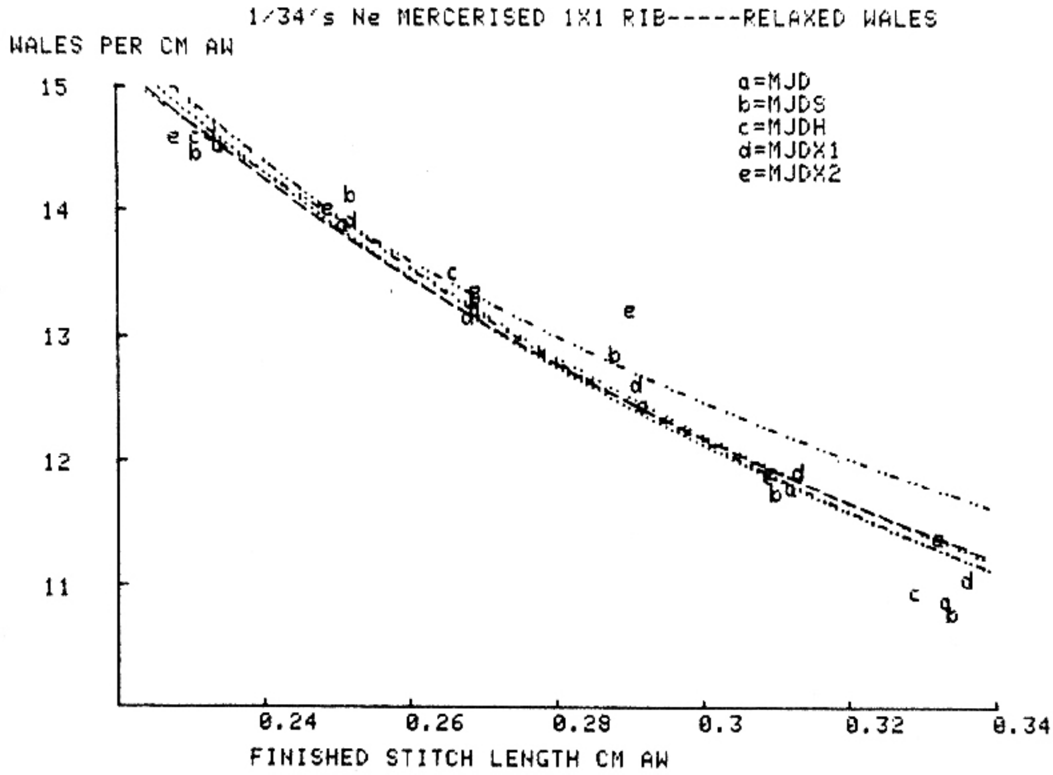
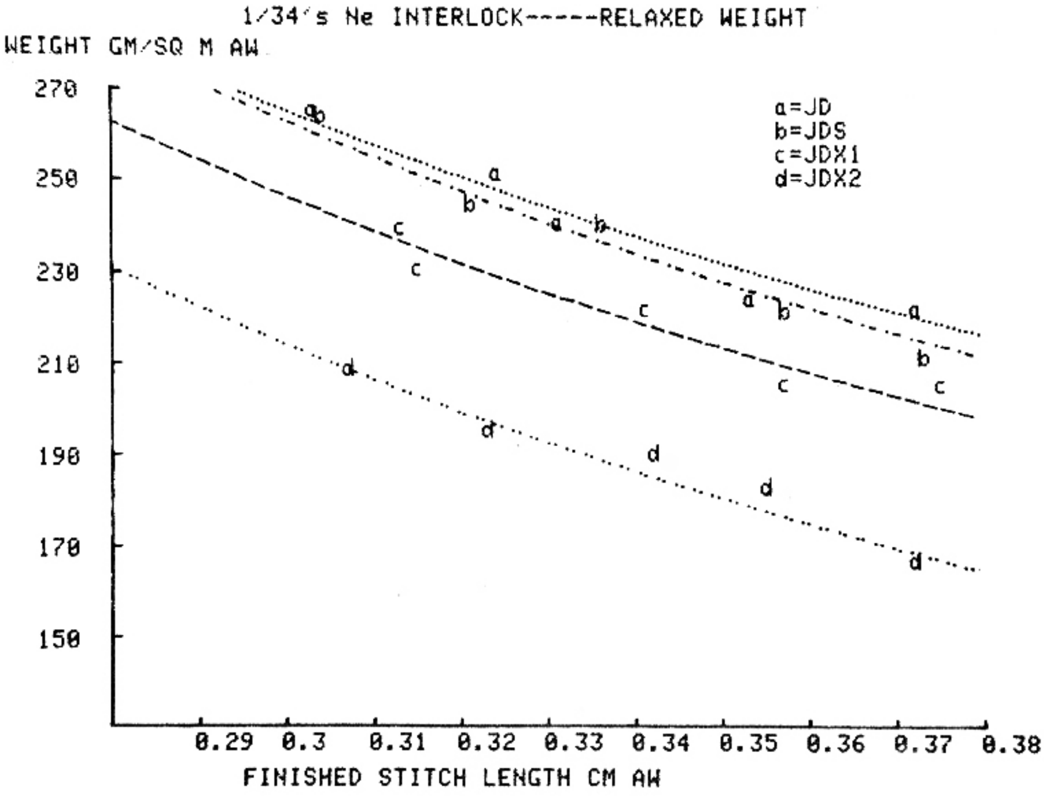


Figure 25



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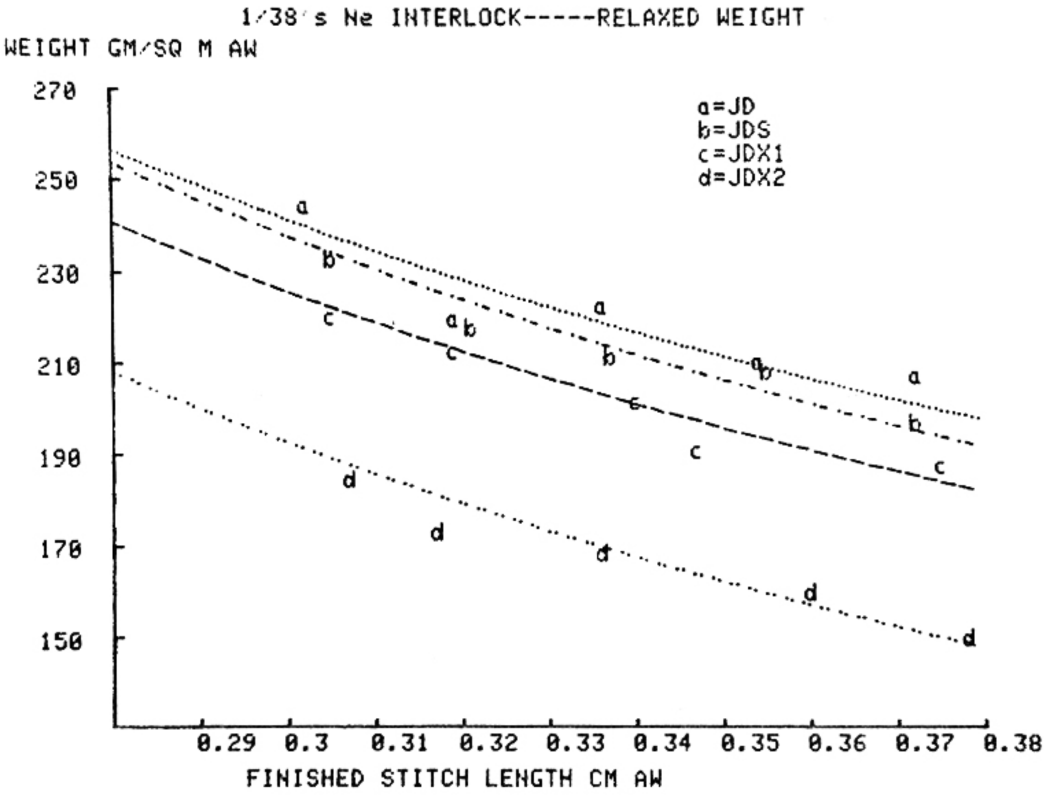

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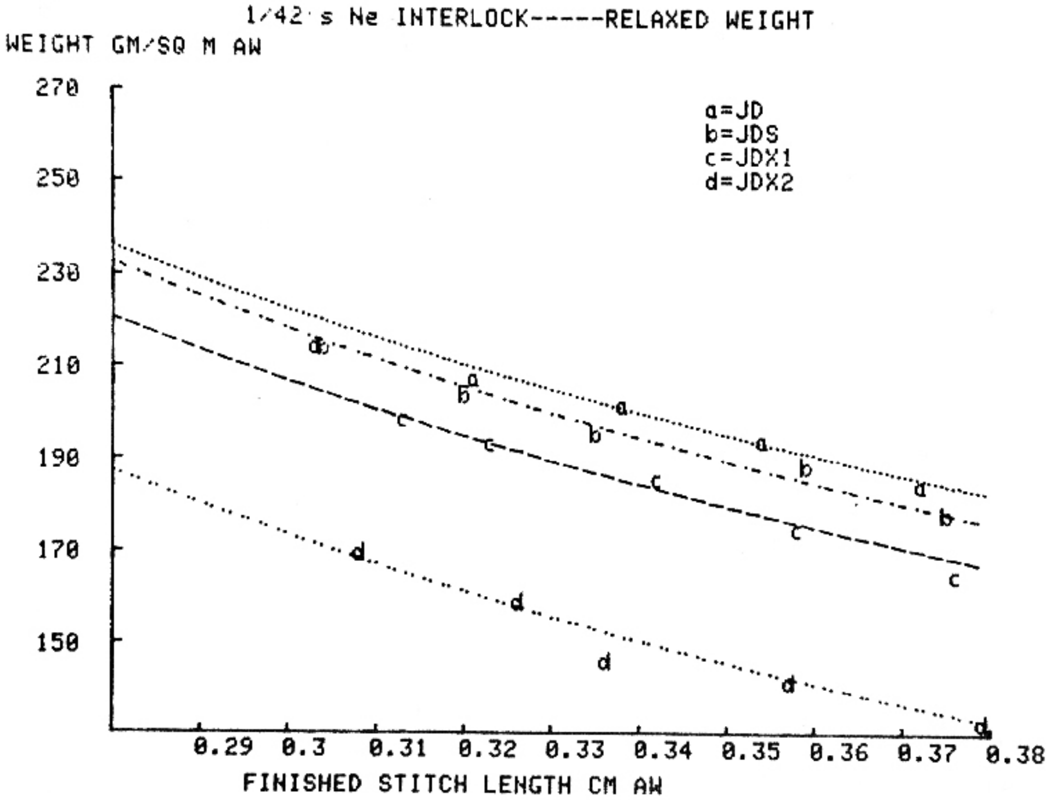

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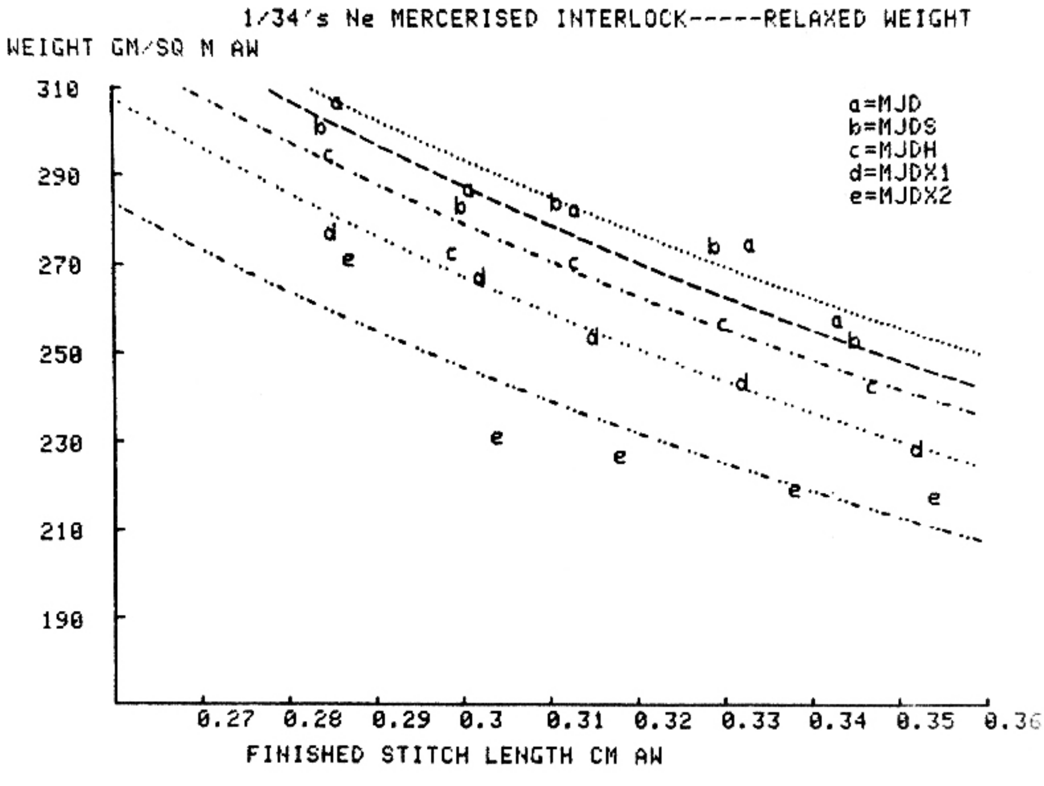

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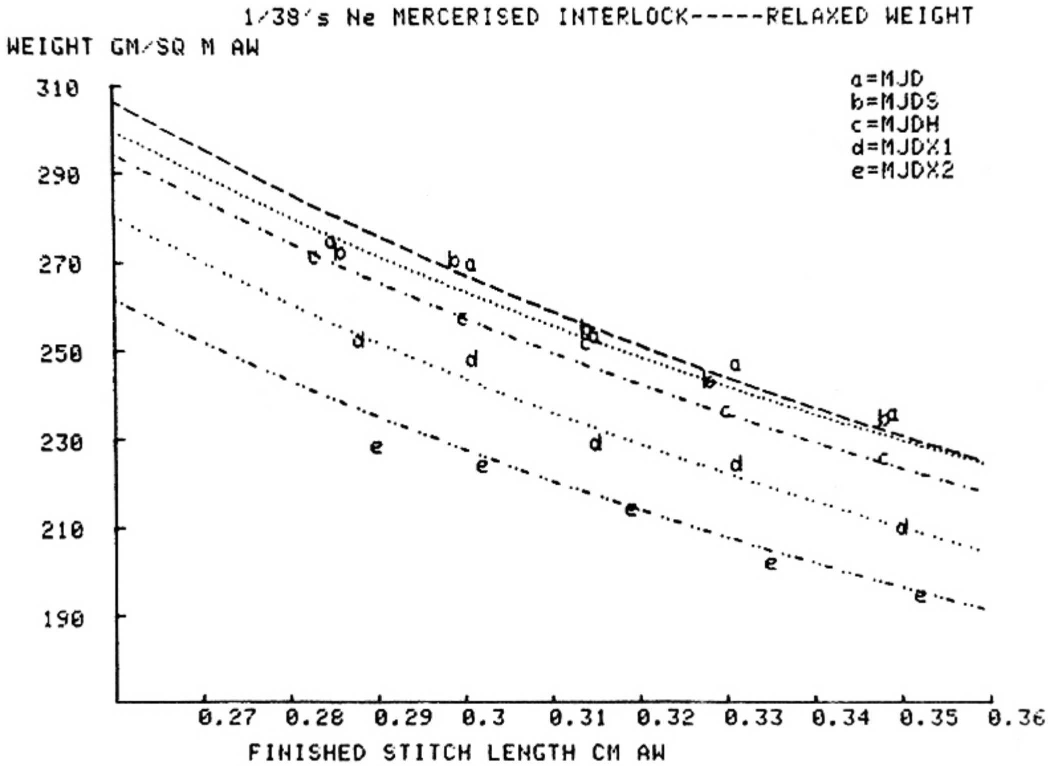

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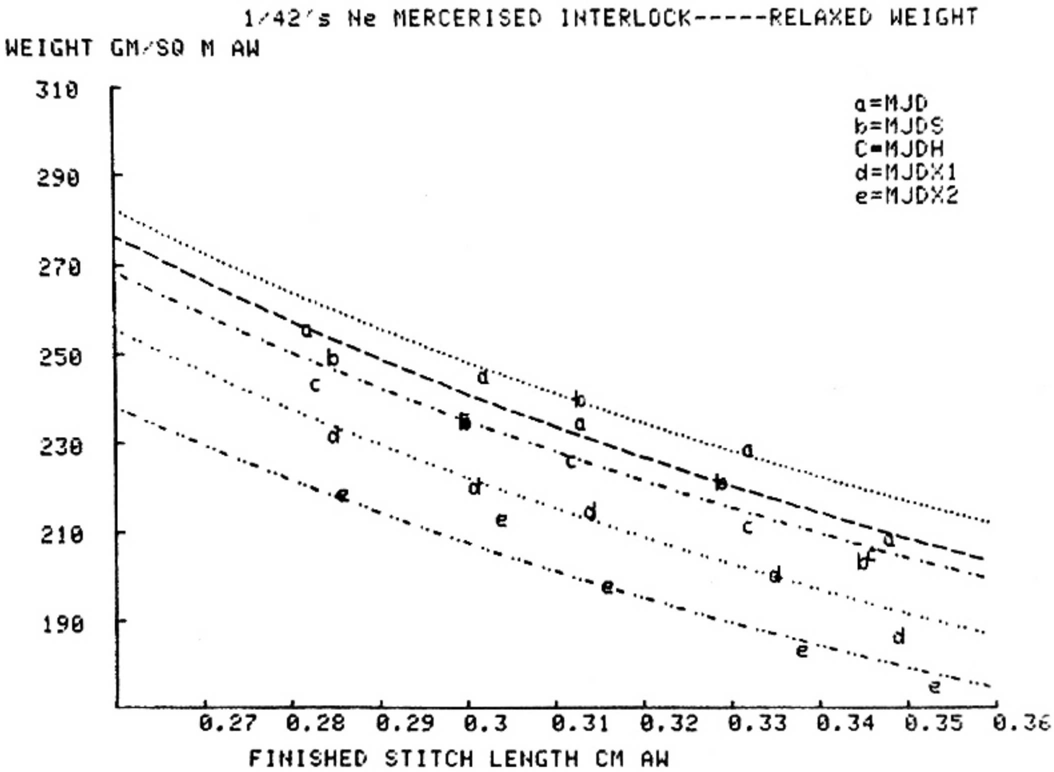

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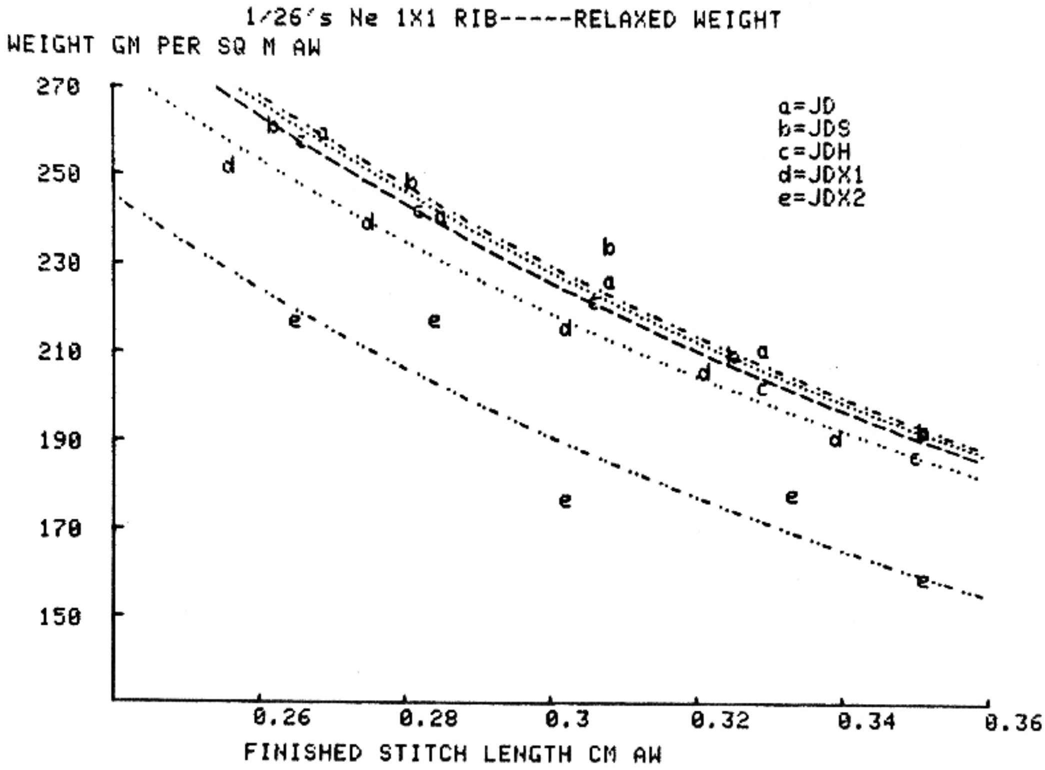

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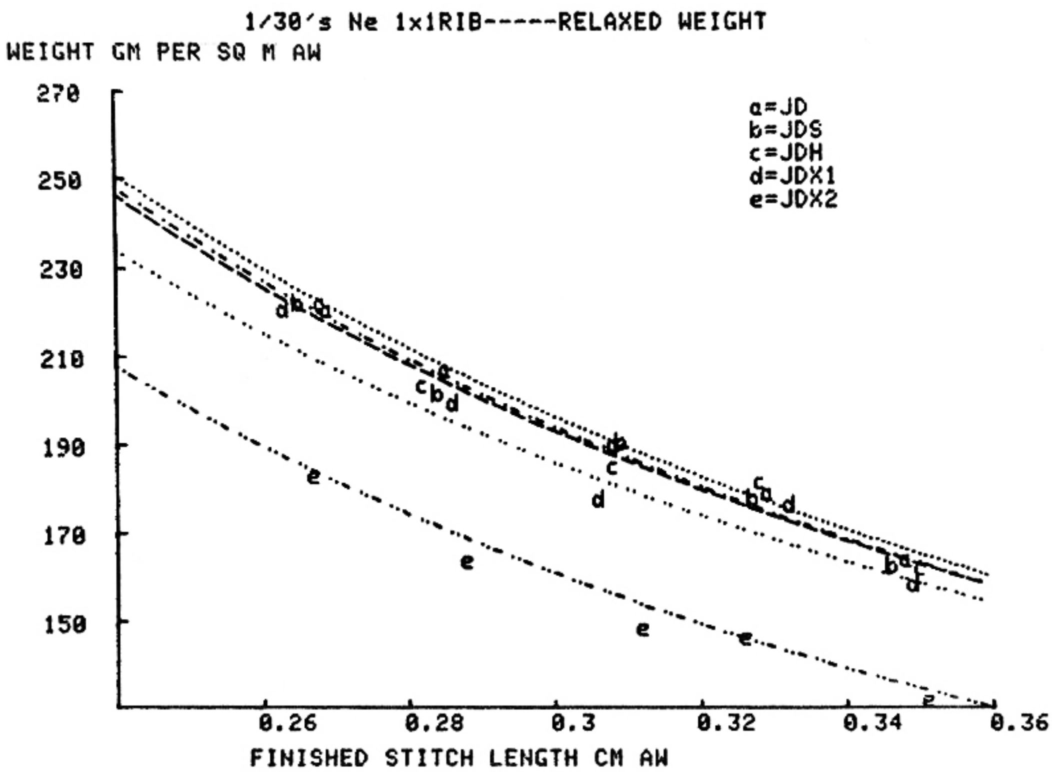

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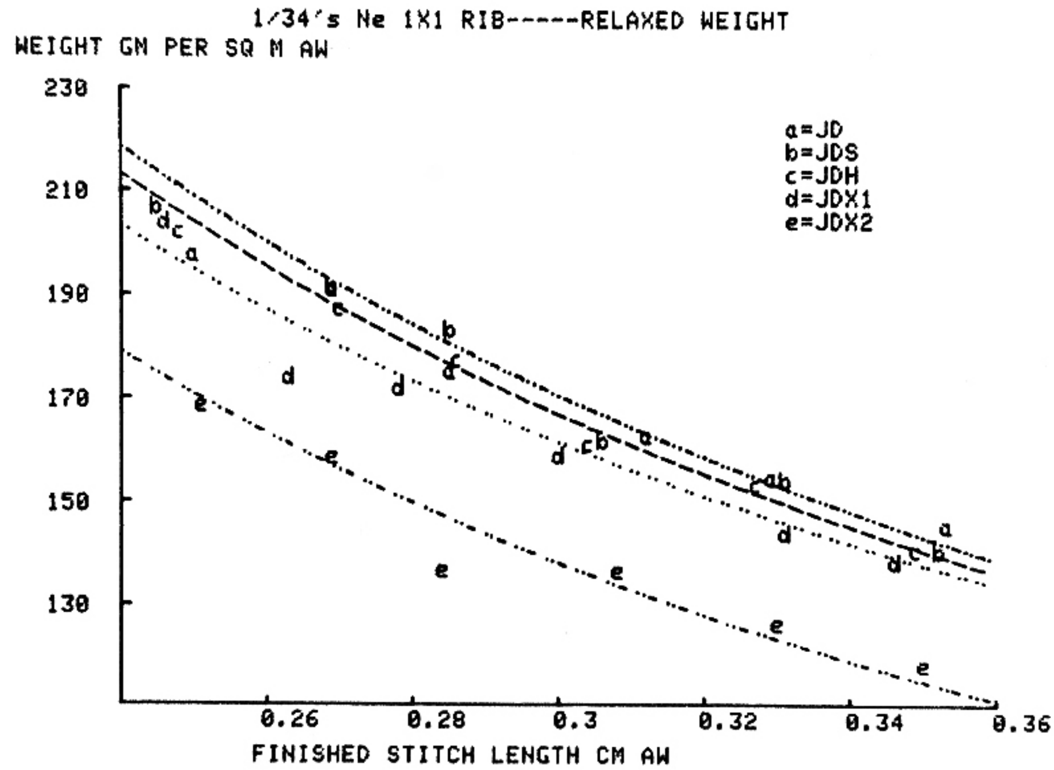

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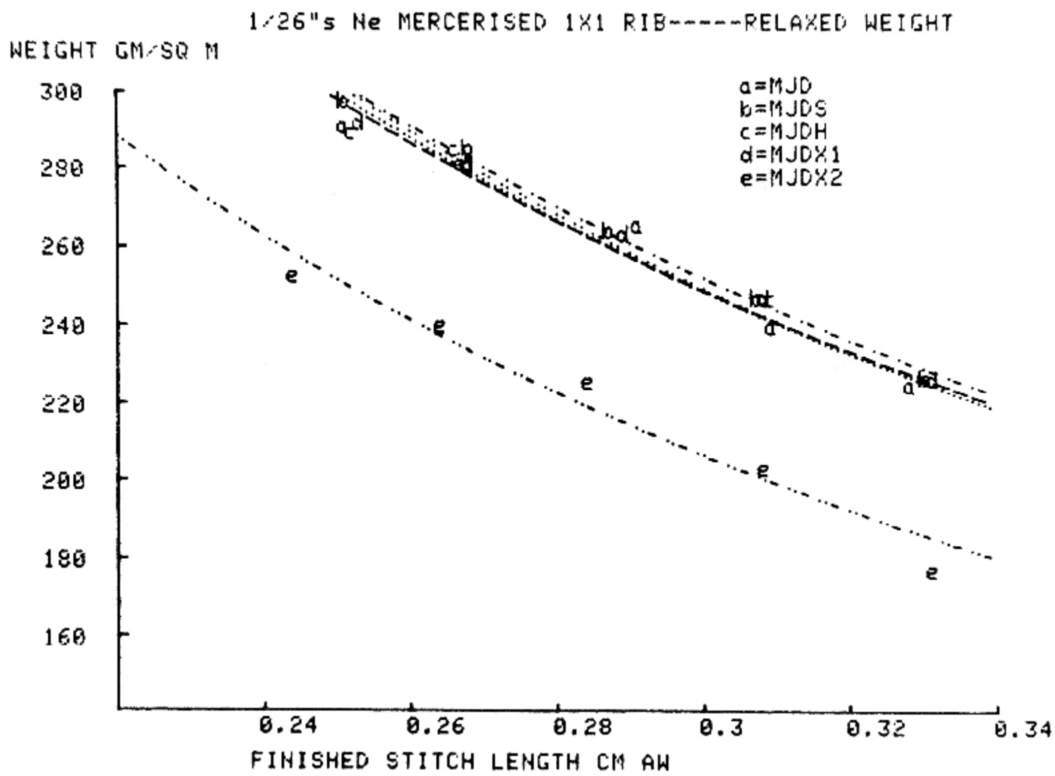

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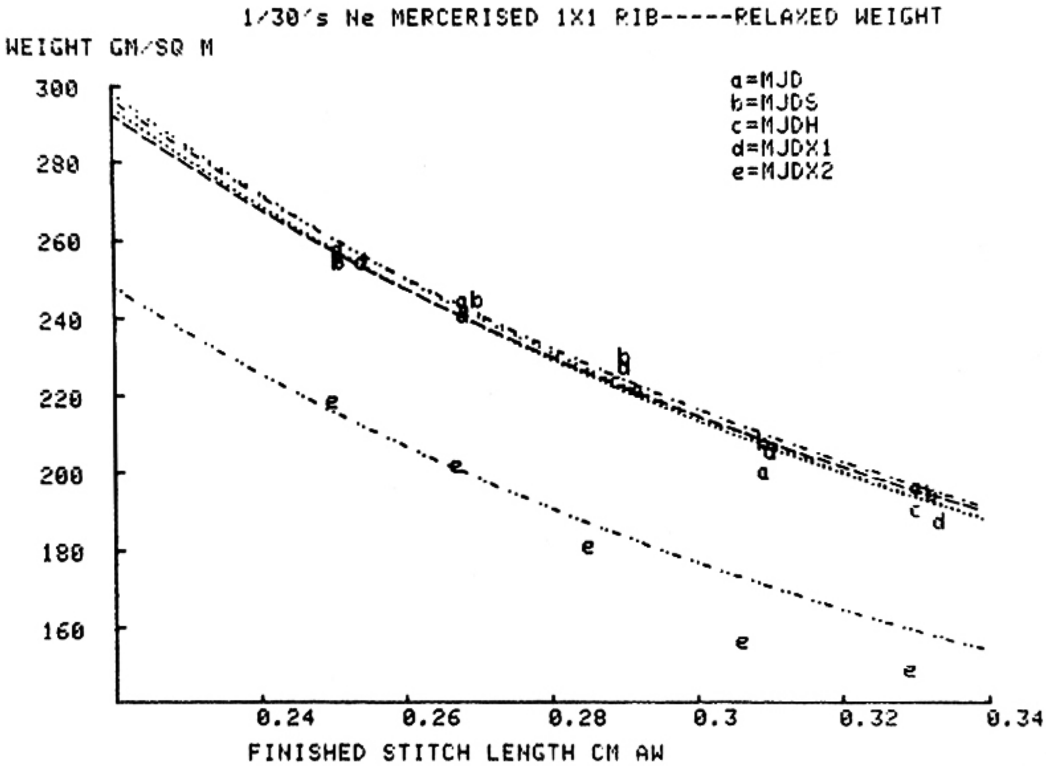

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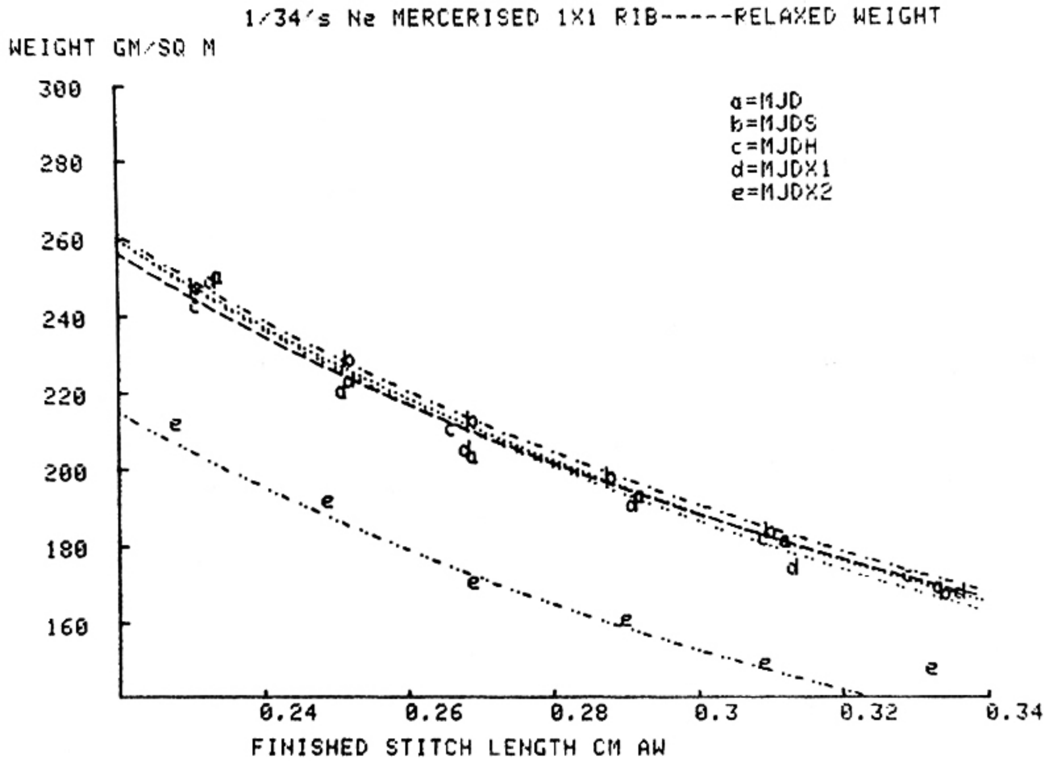

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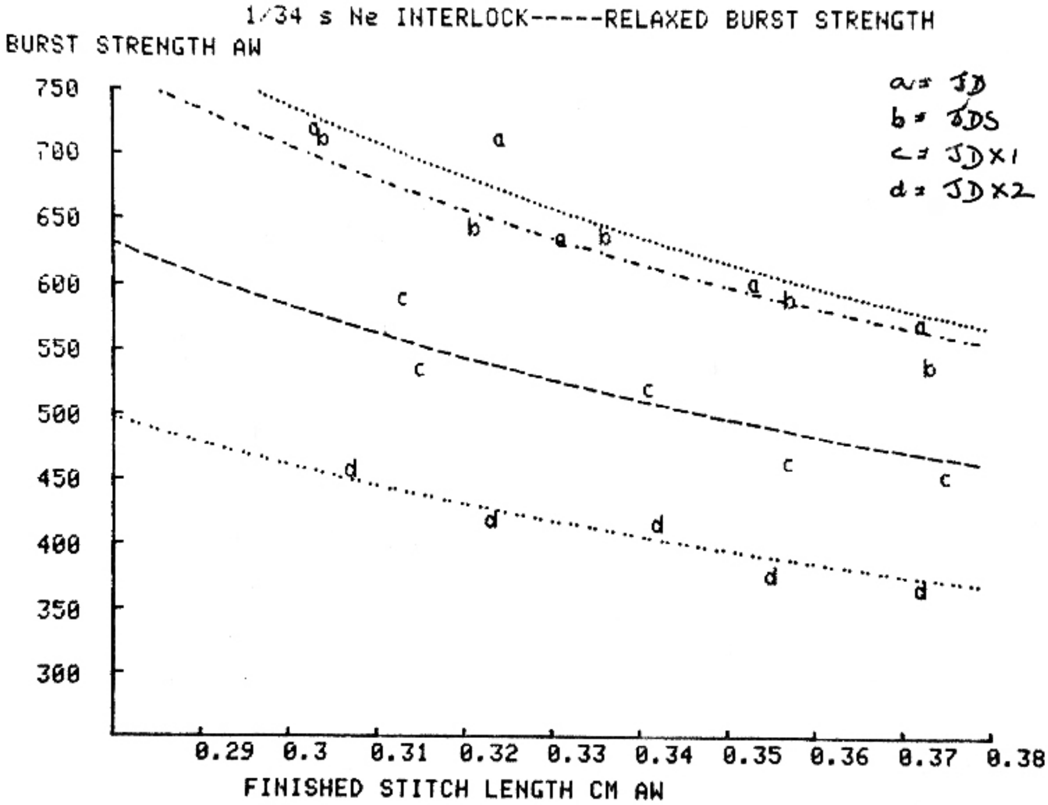

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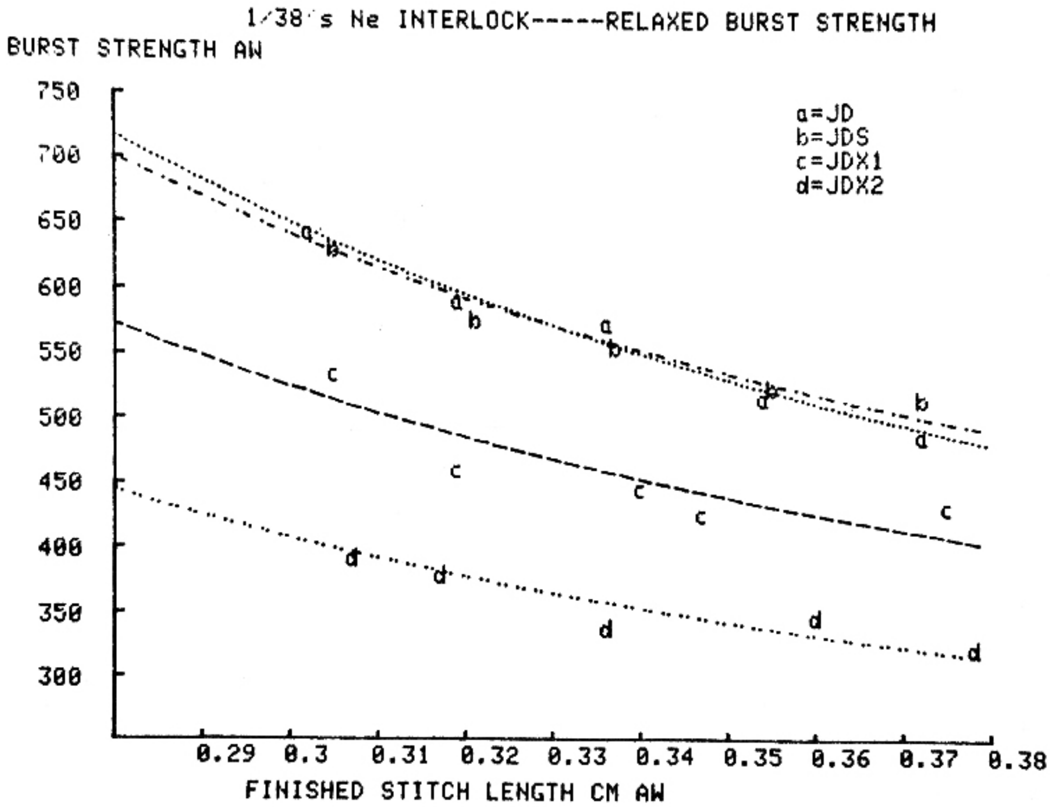

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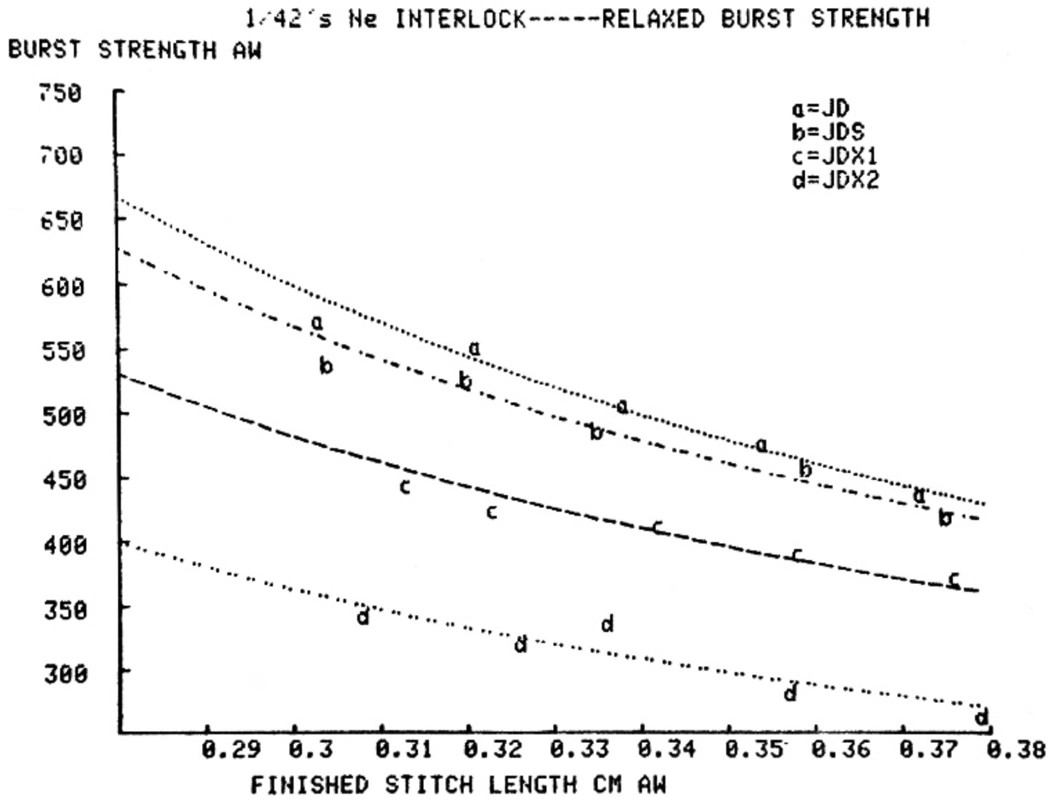

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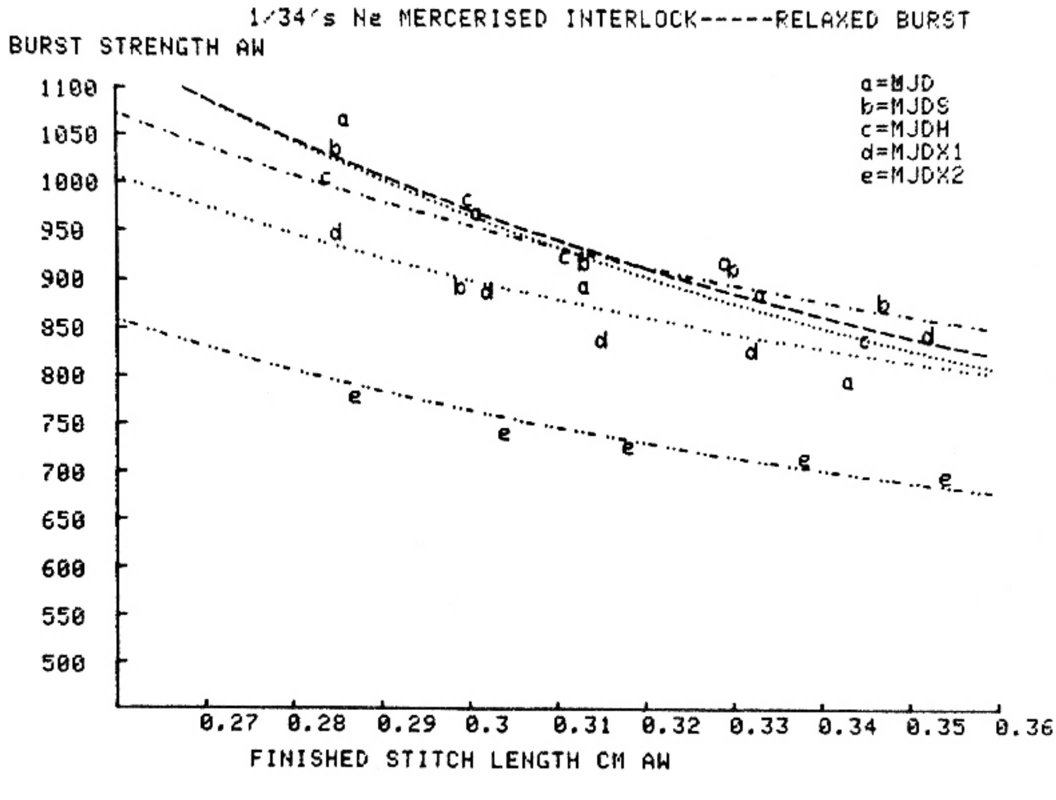

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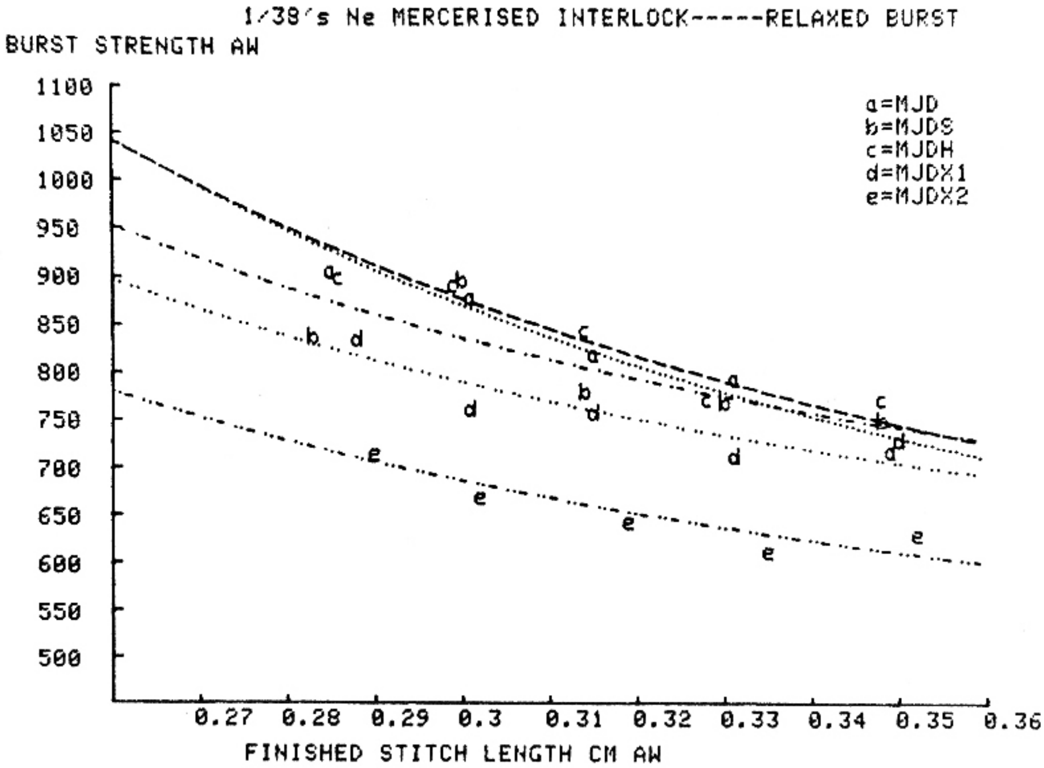

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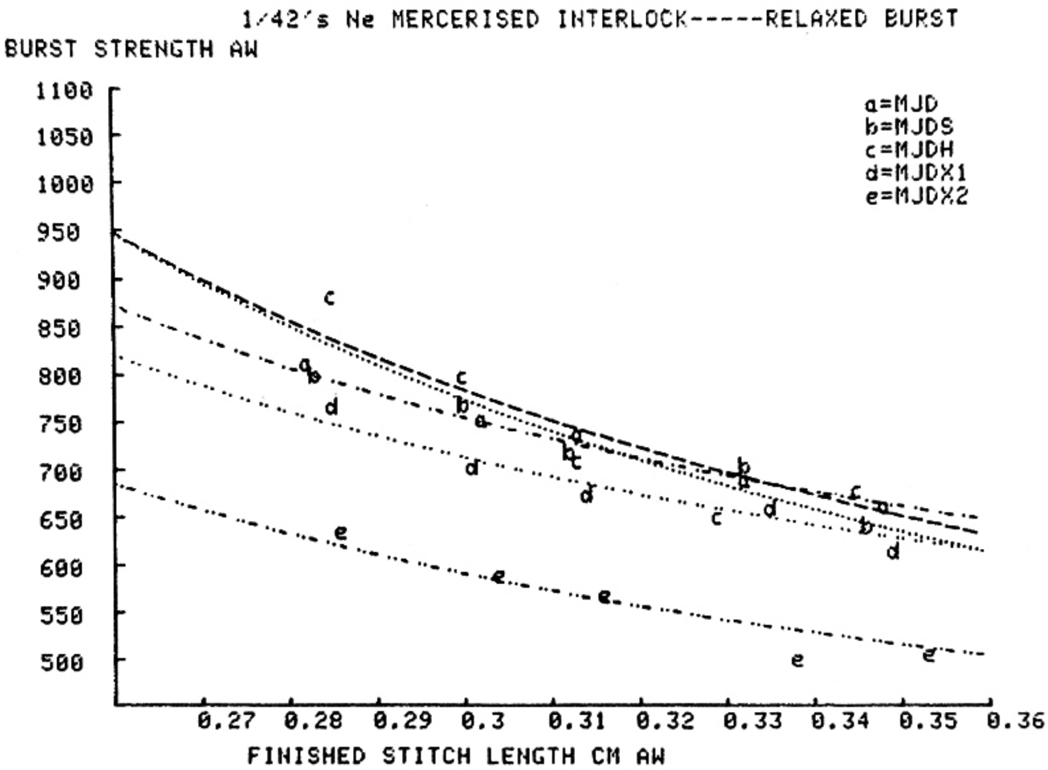

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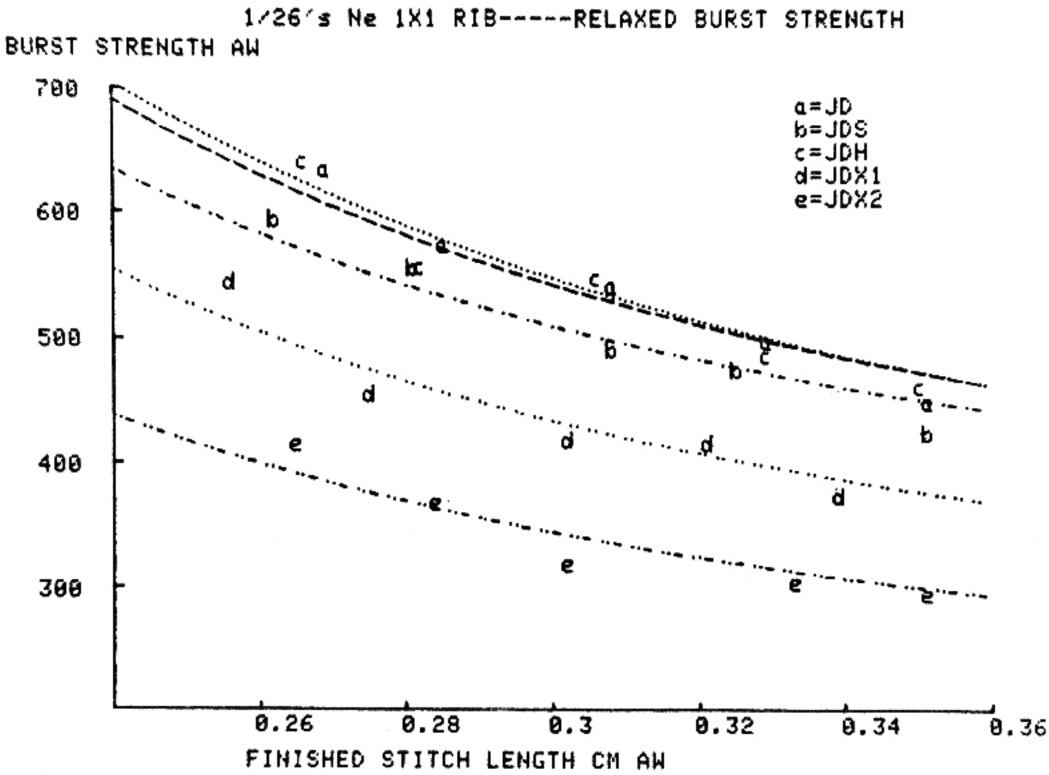

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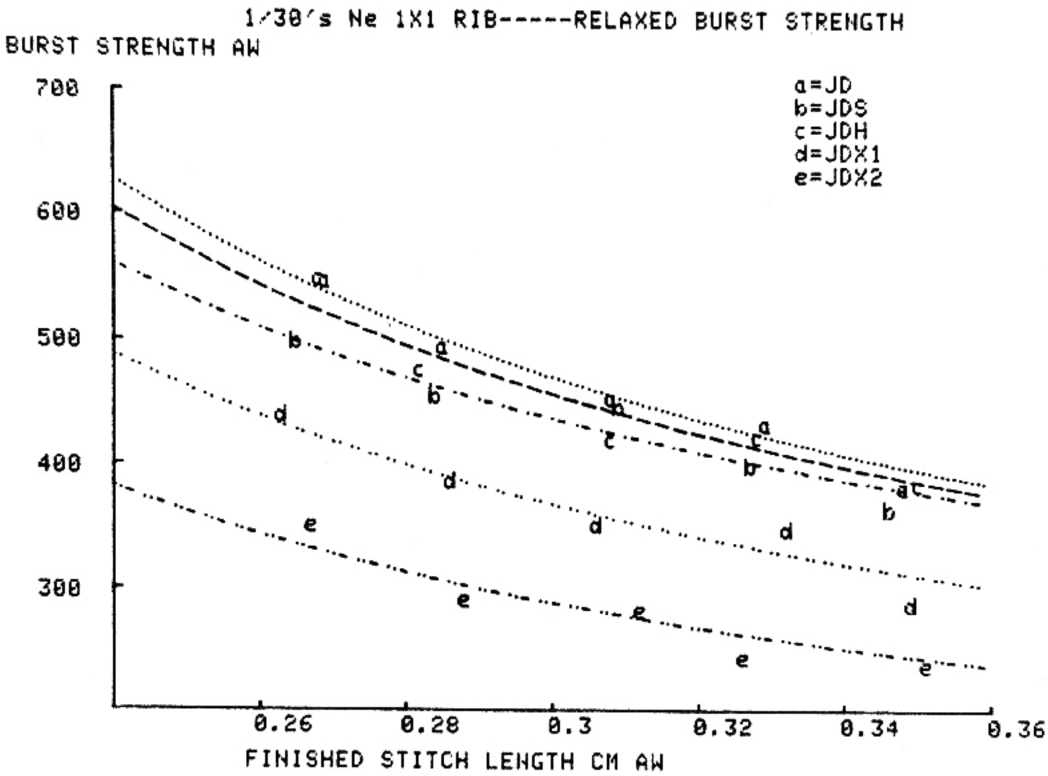

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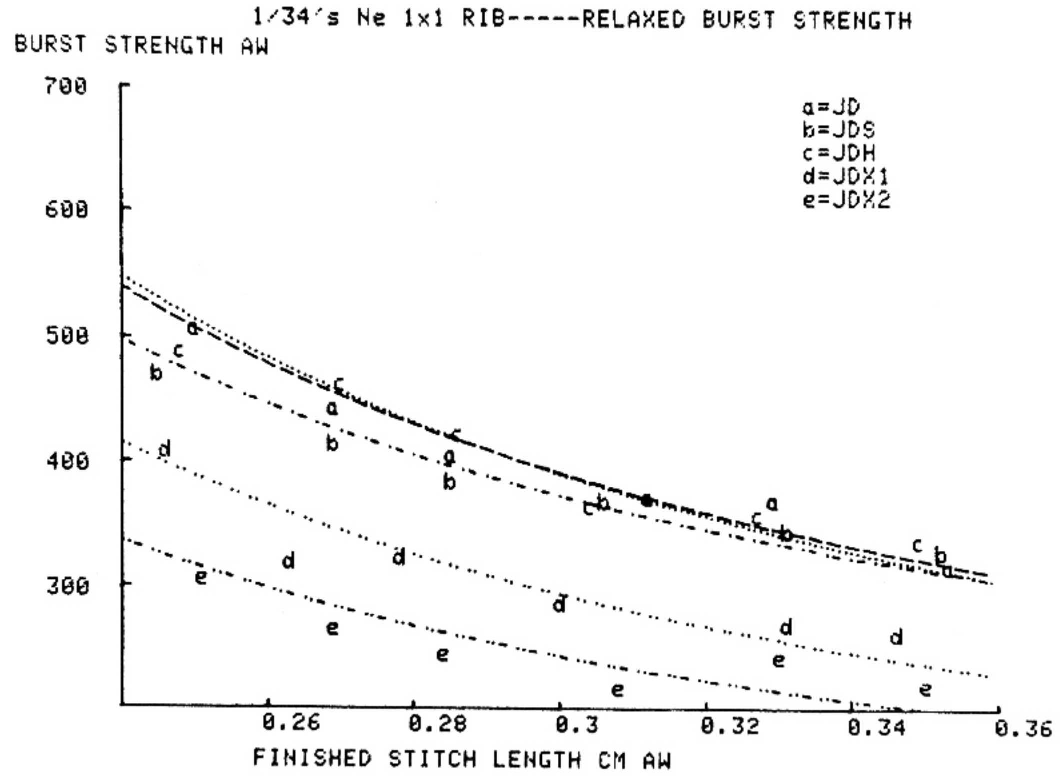

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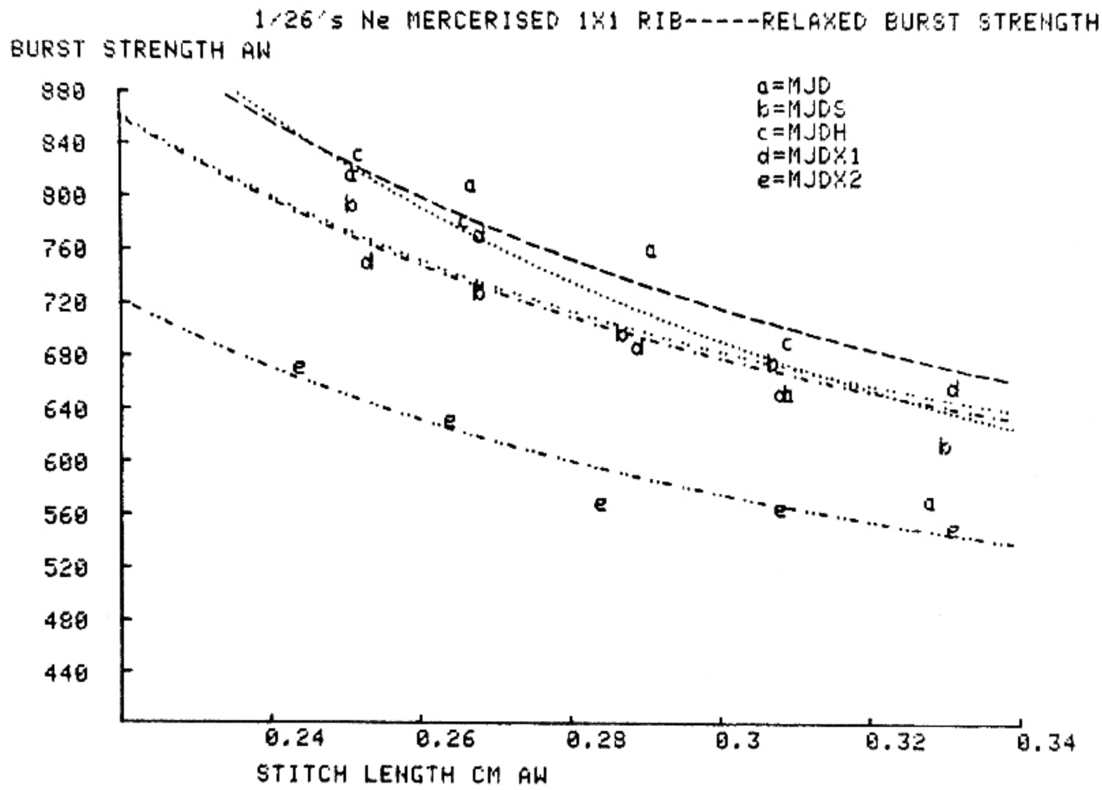

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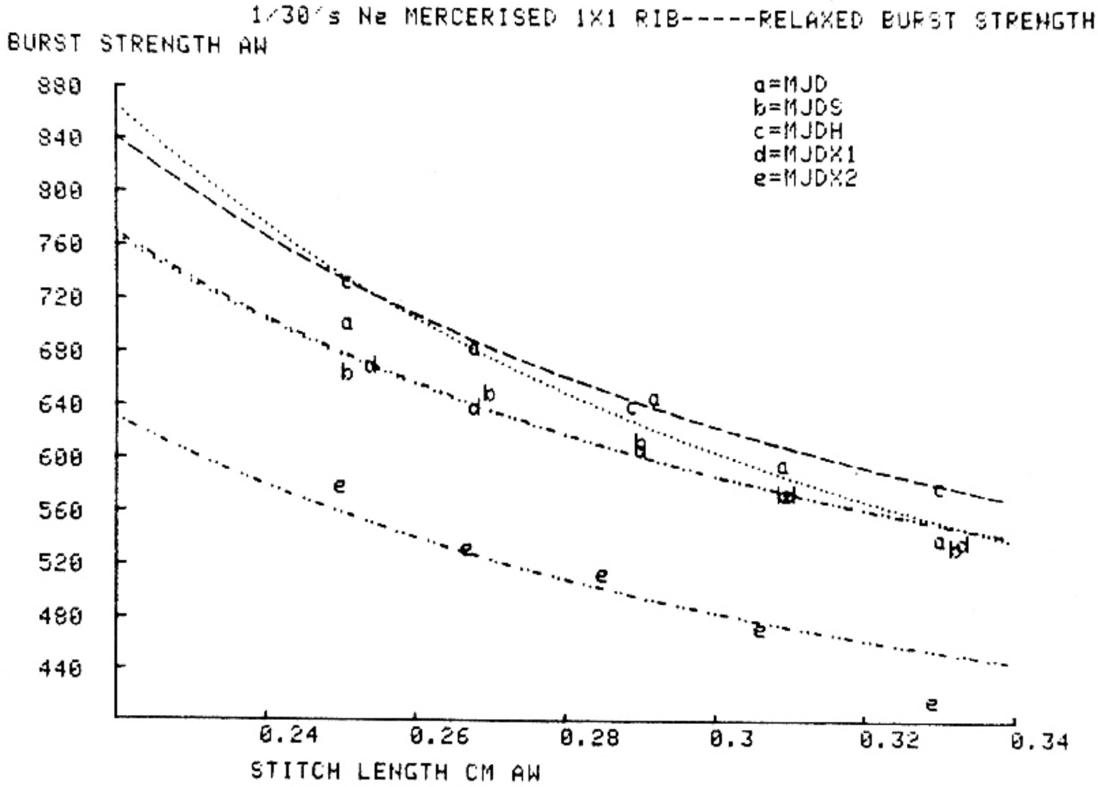

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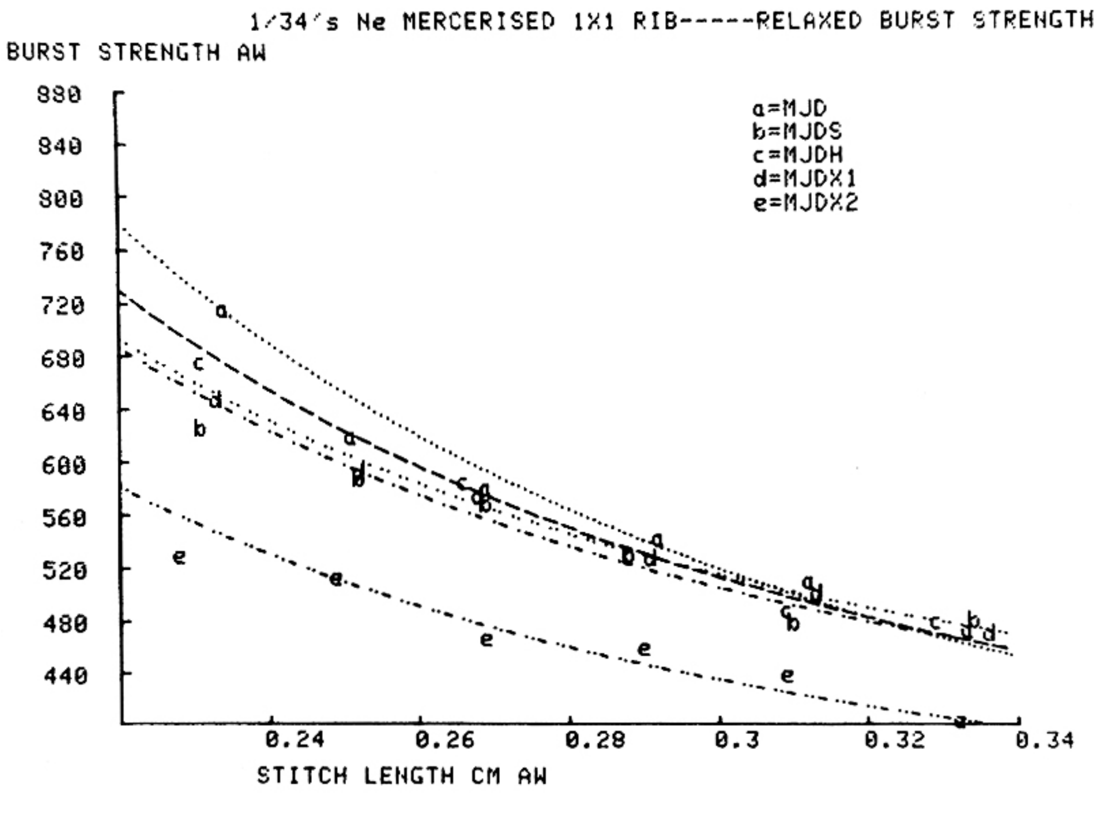

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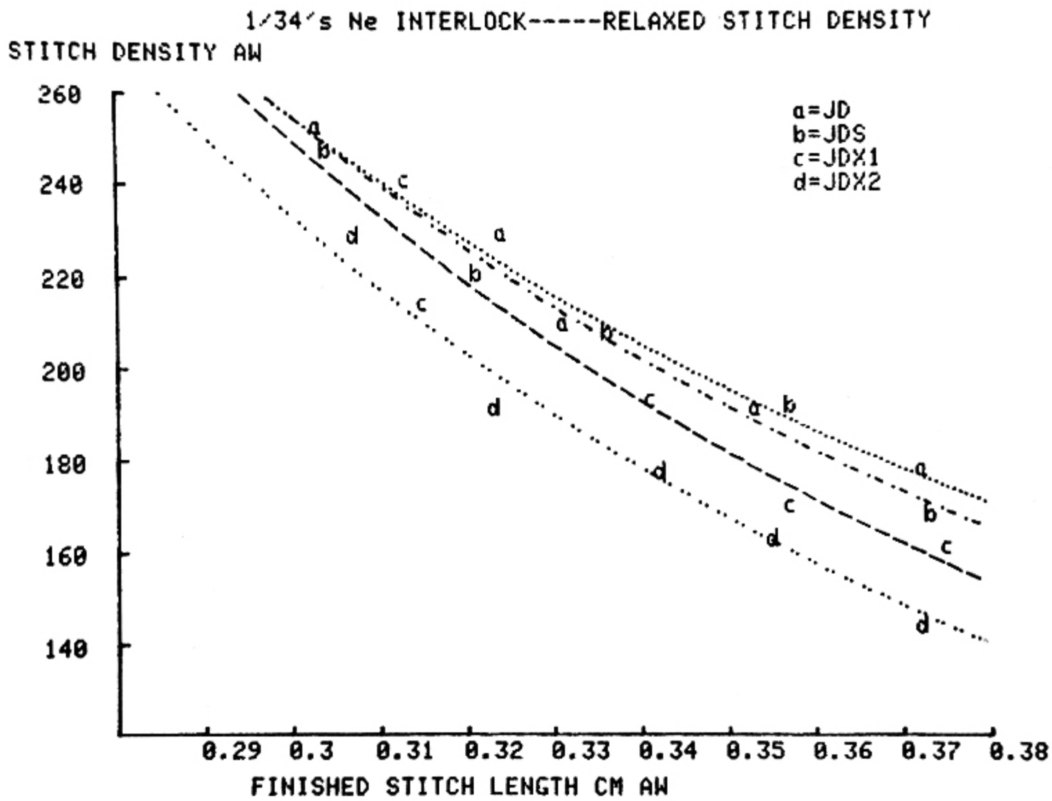

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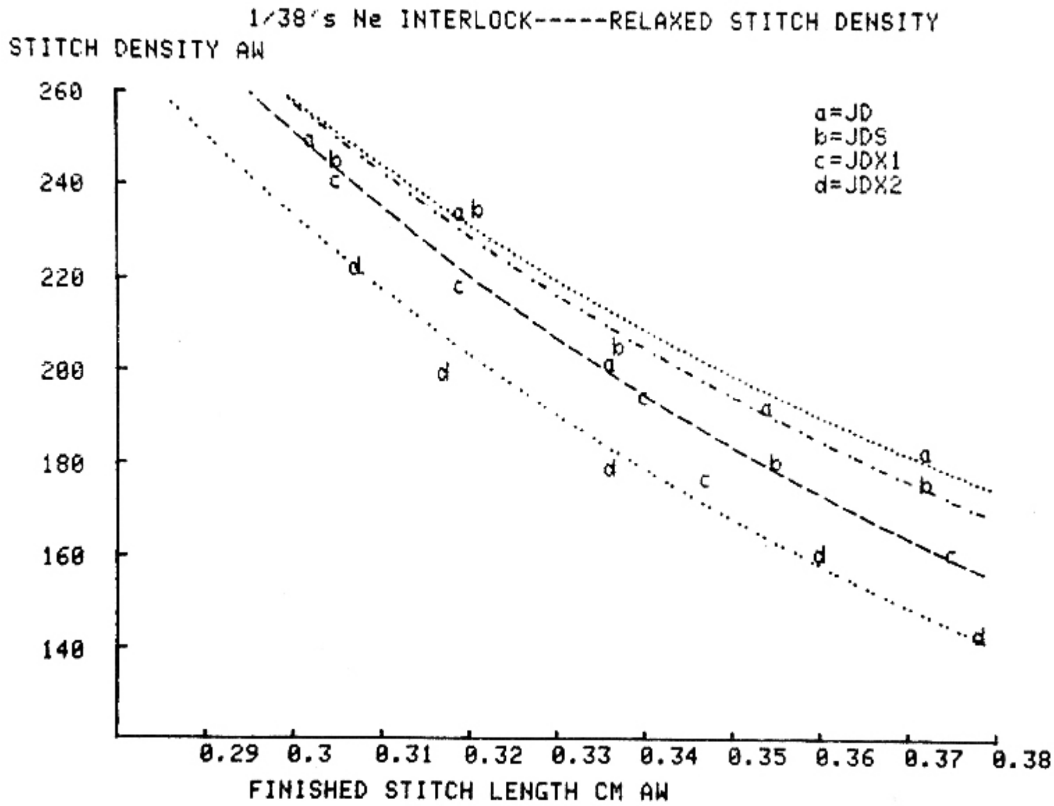

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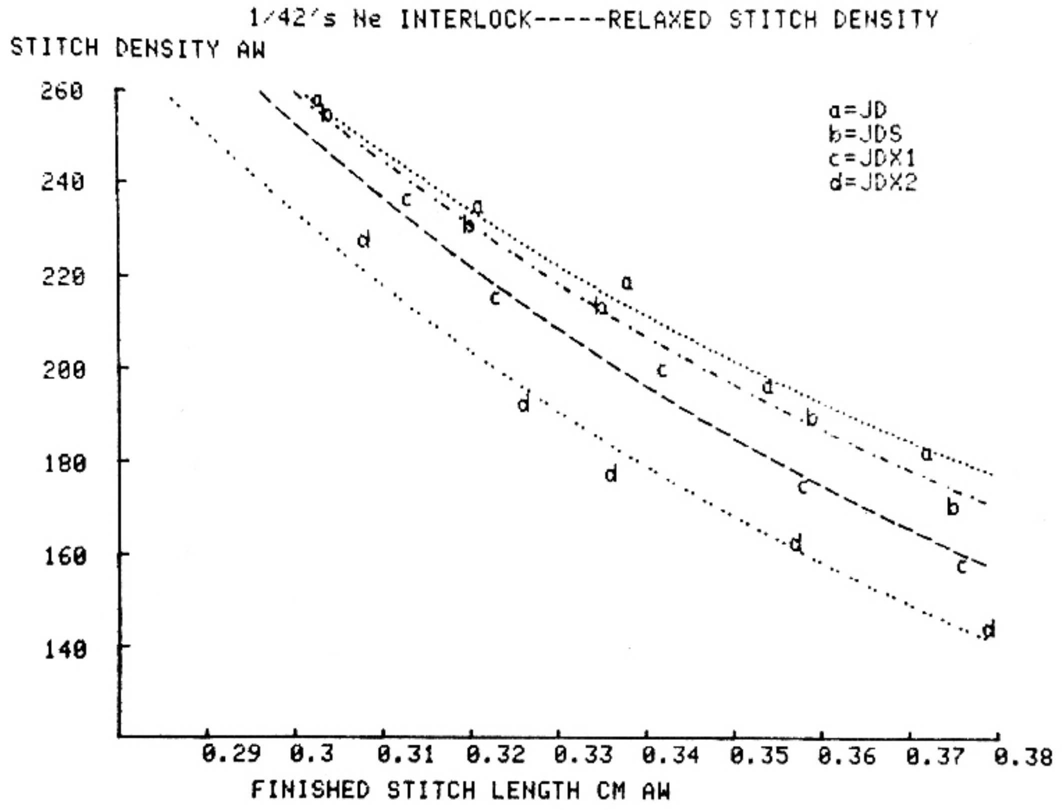

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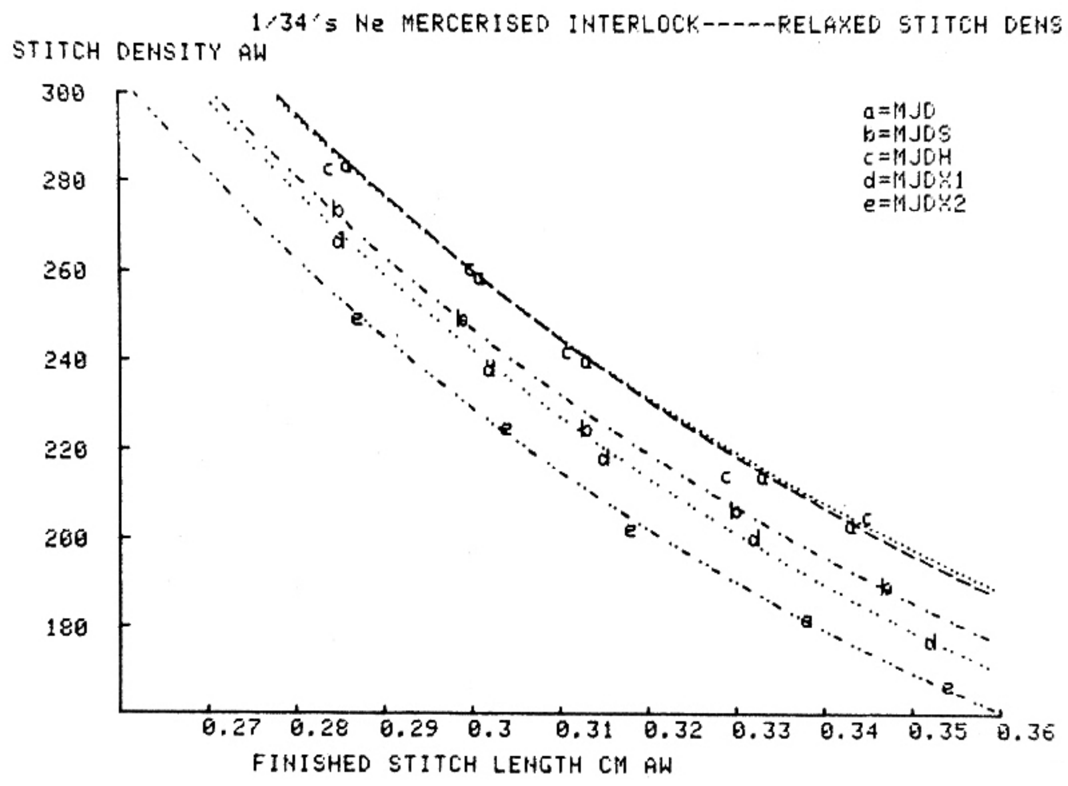

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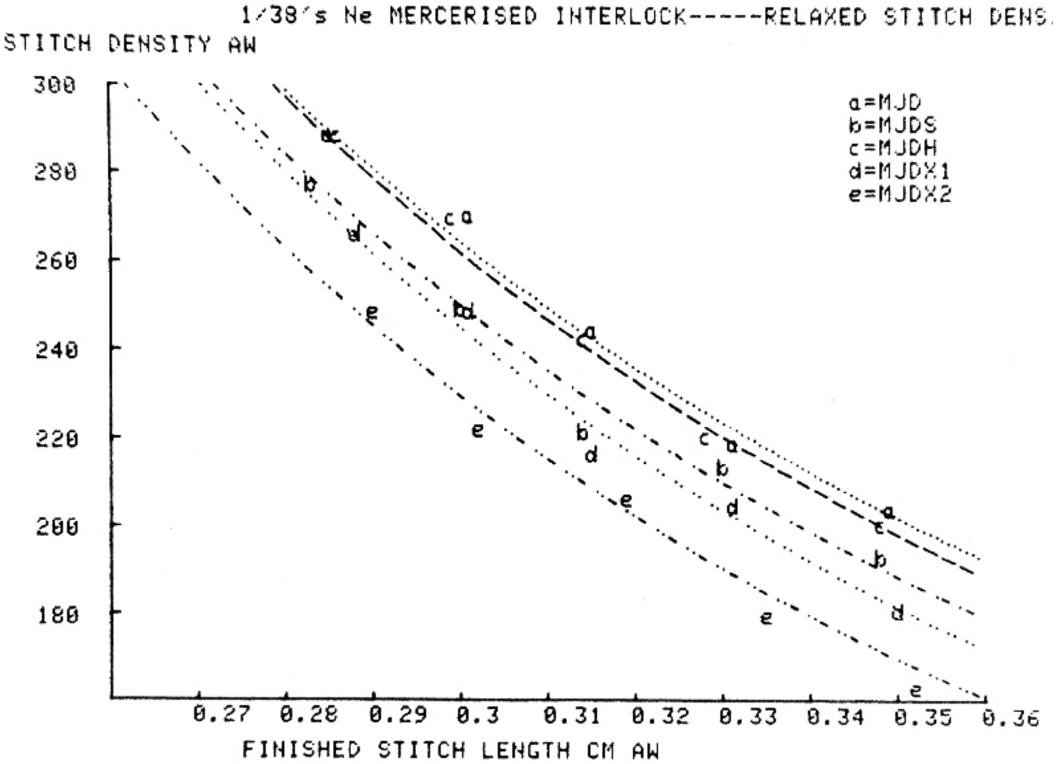

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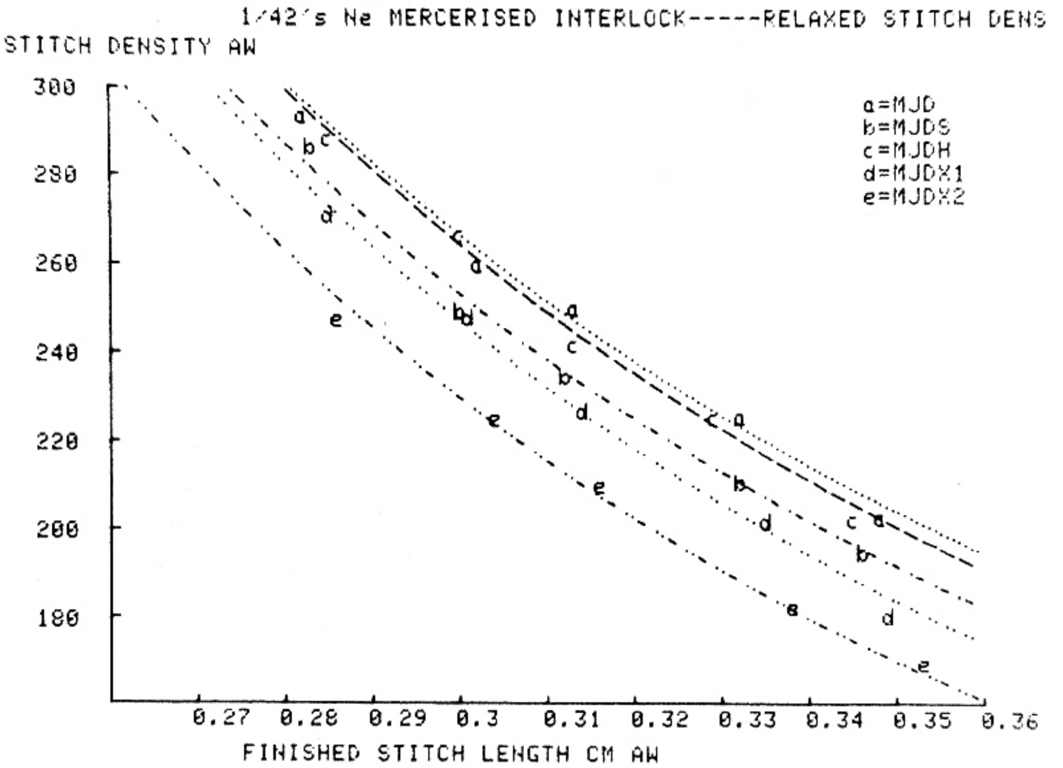

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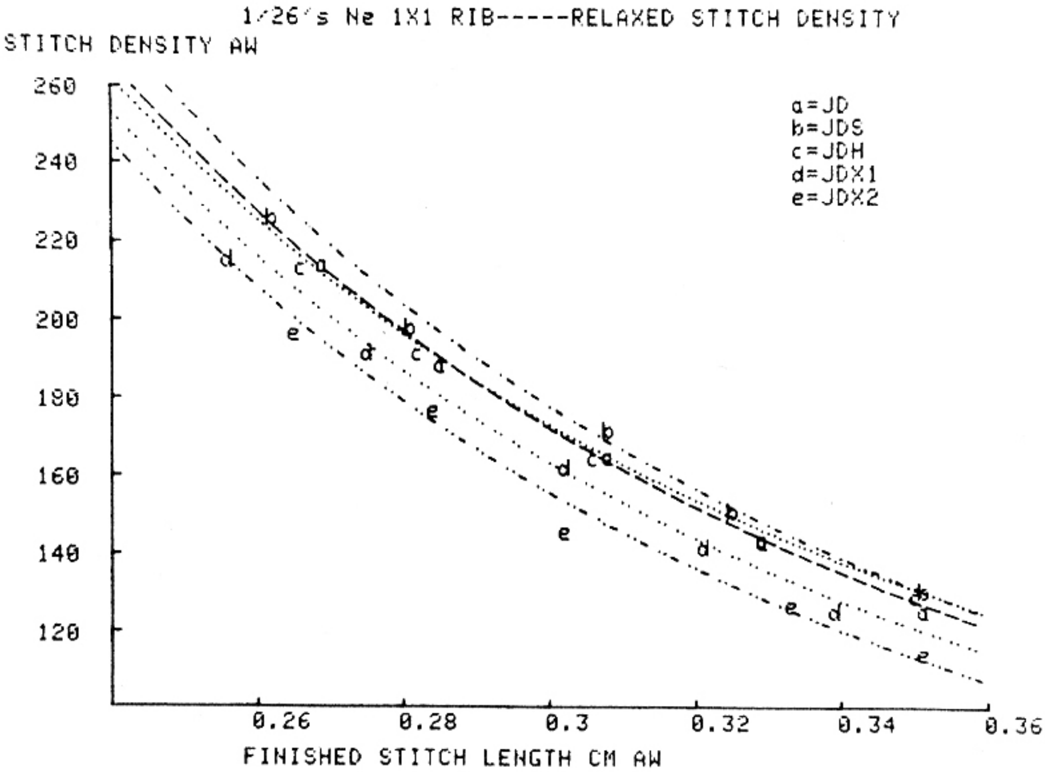

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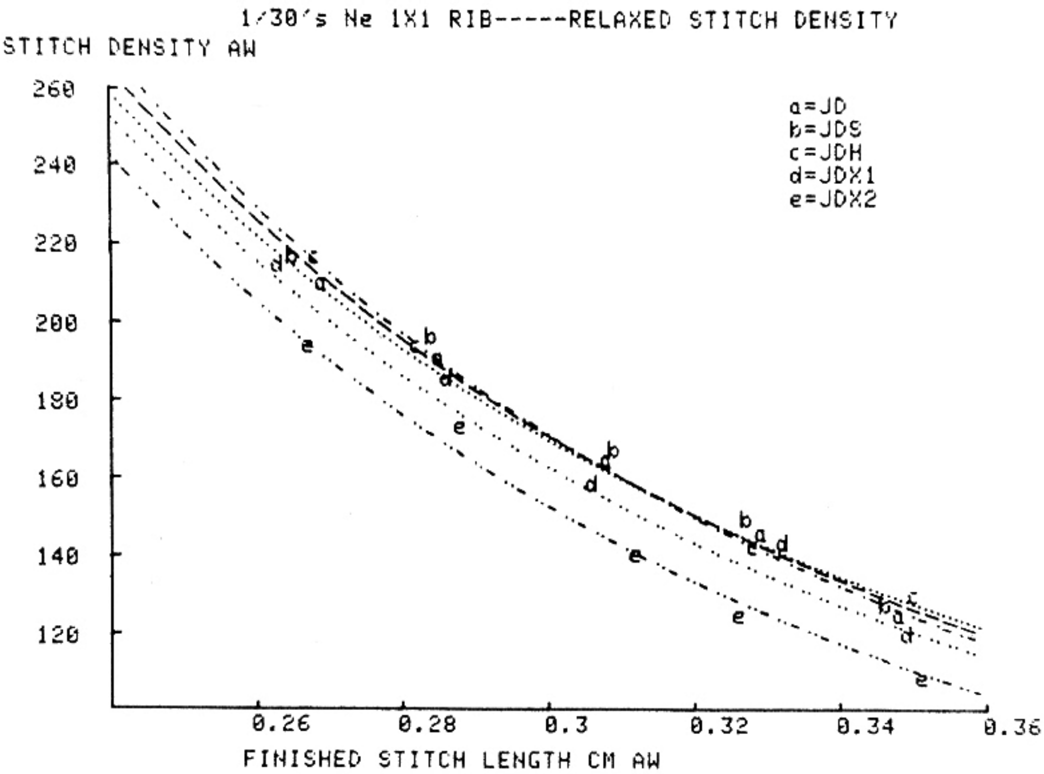

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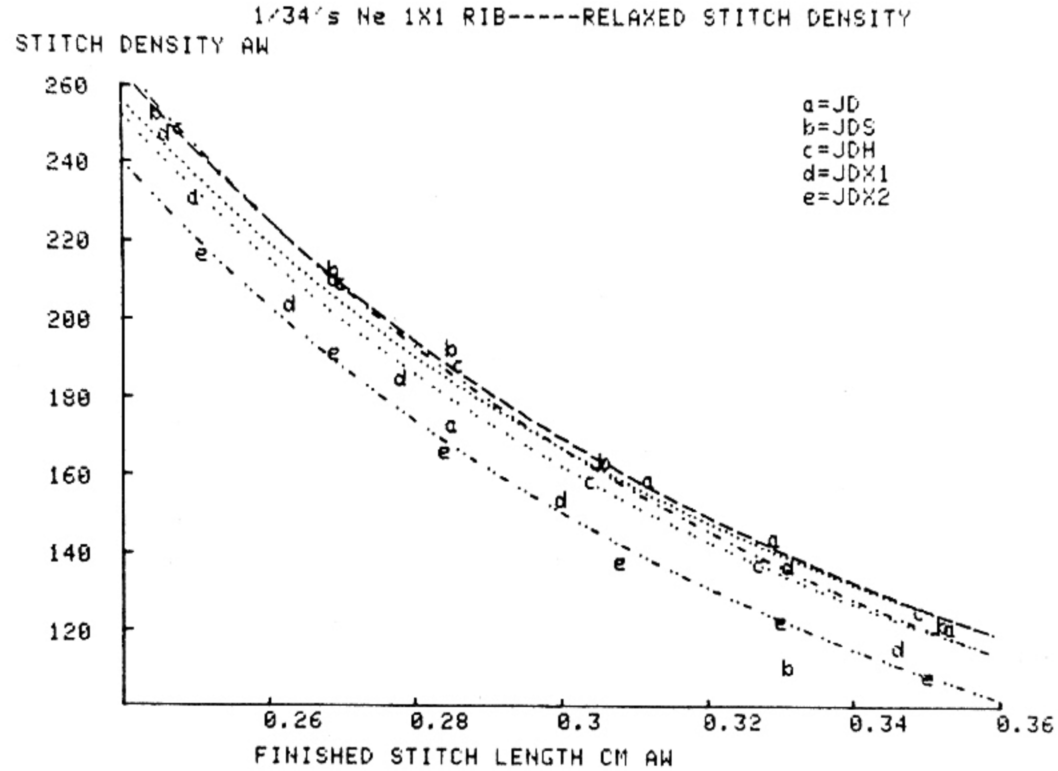

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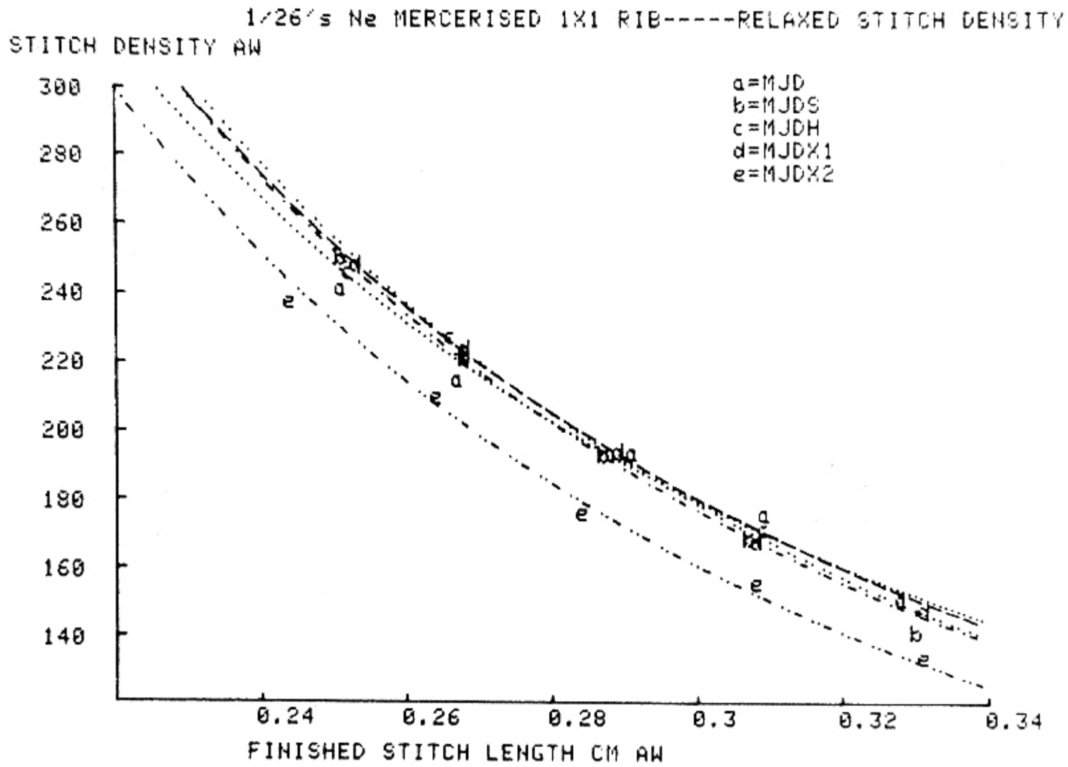

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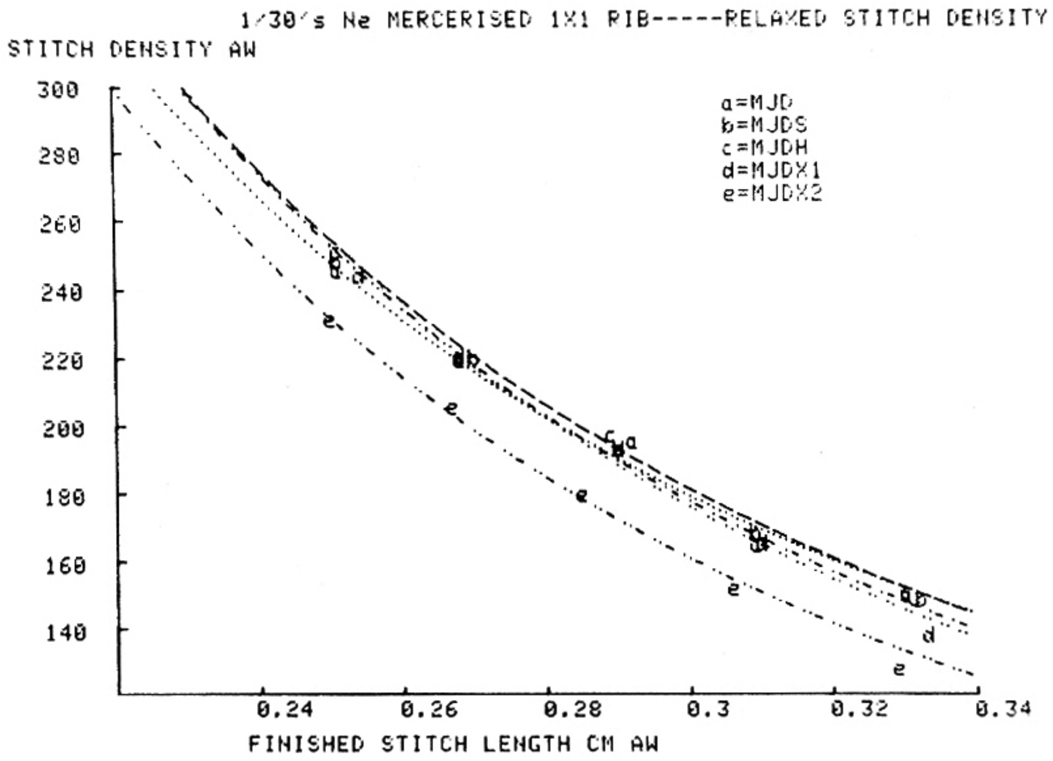

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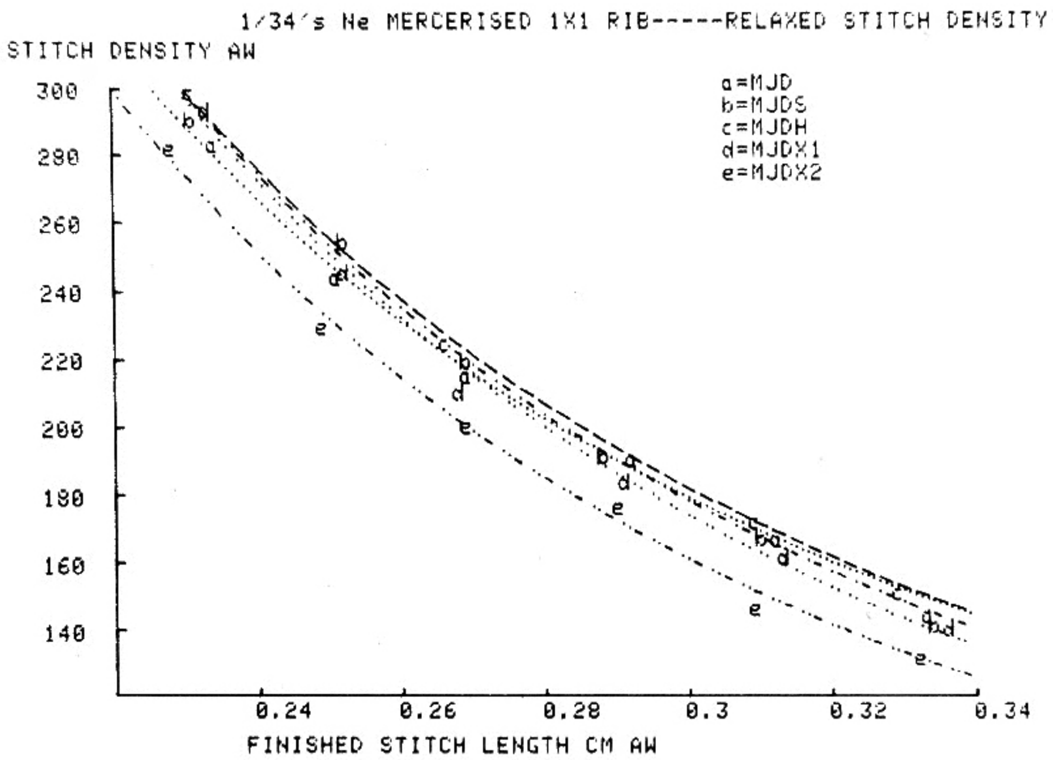

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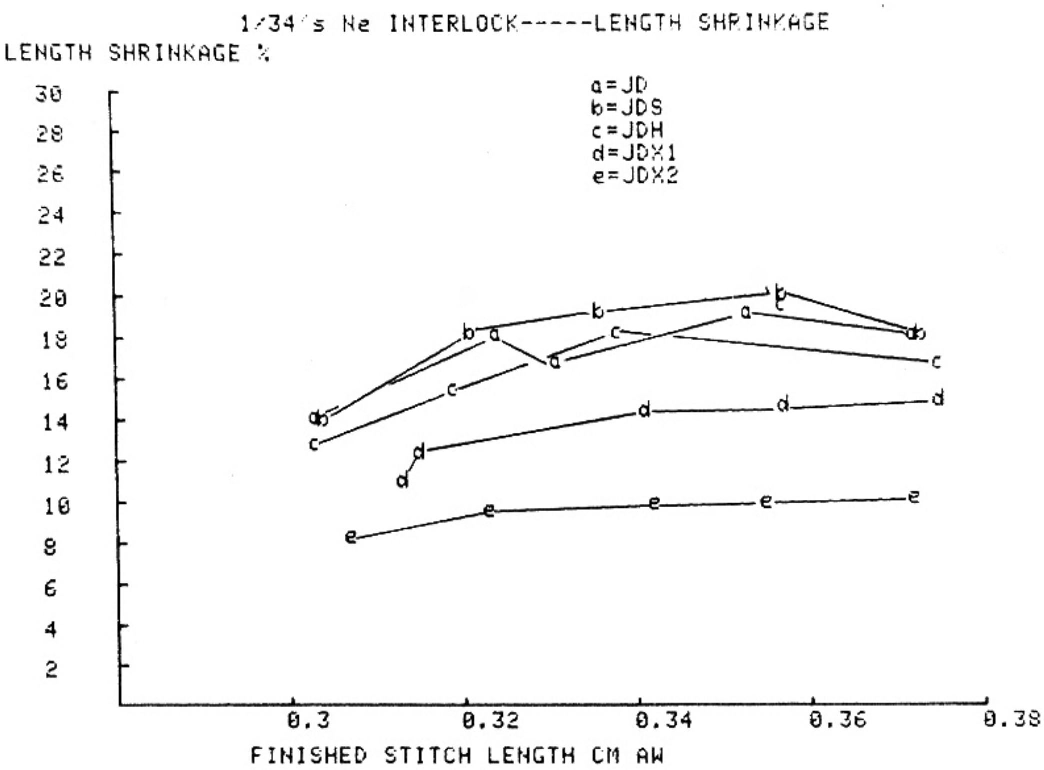

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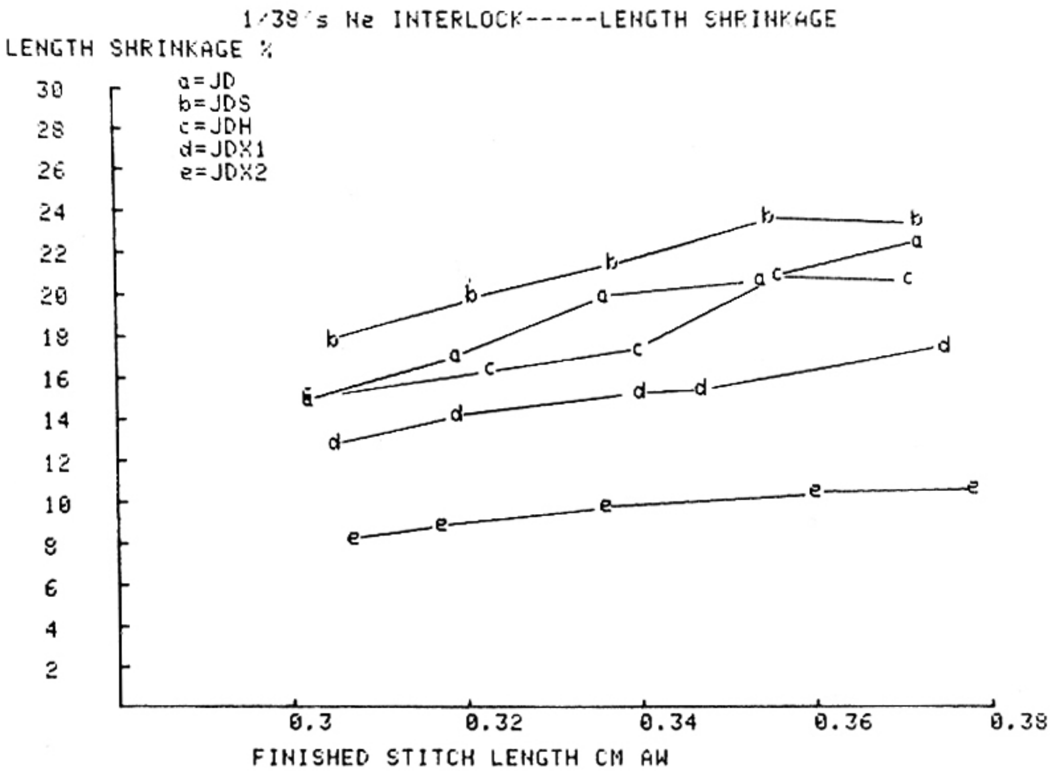

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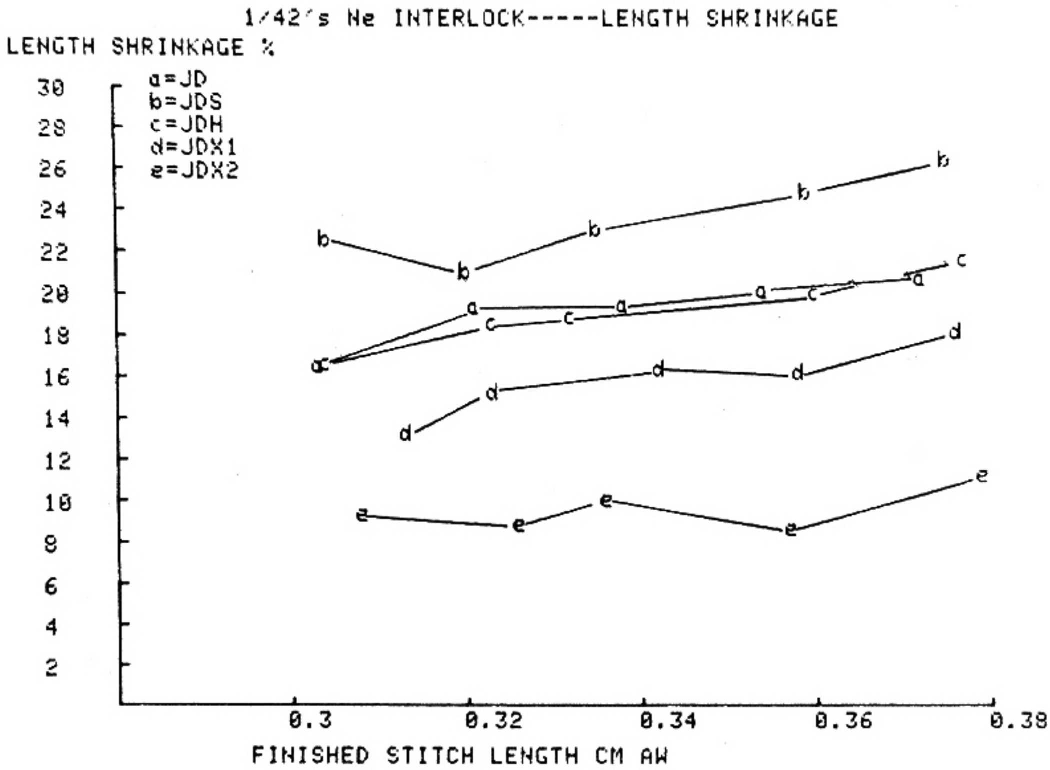

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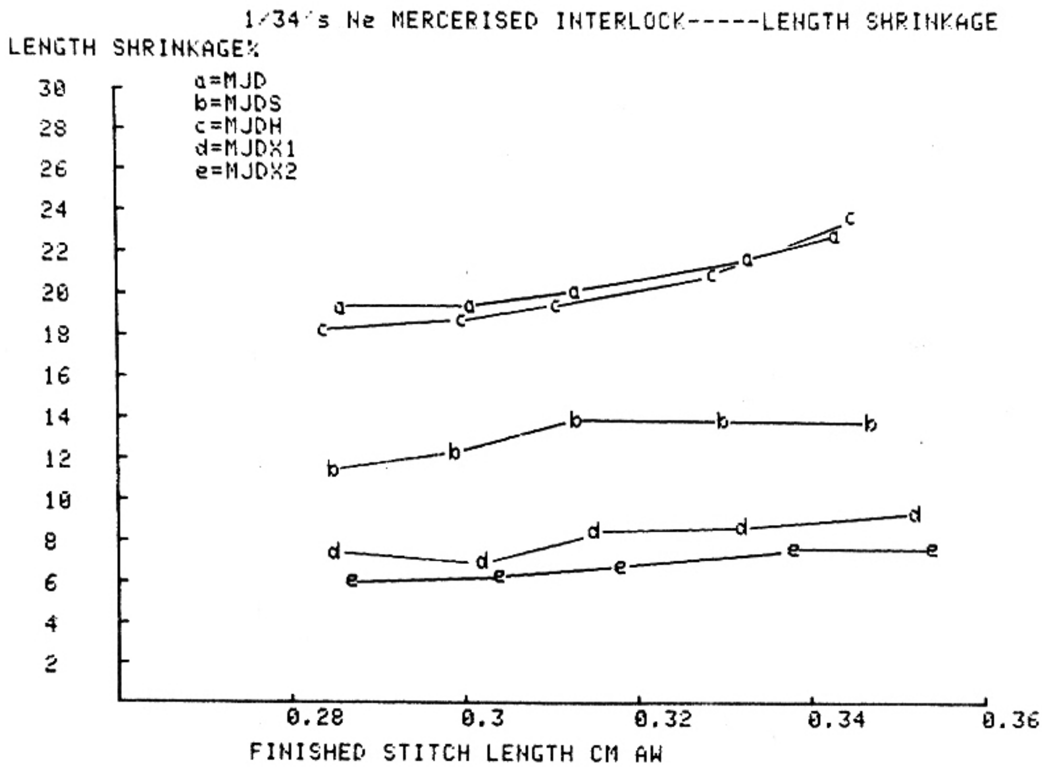

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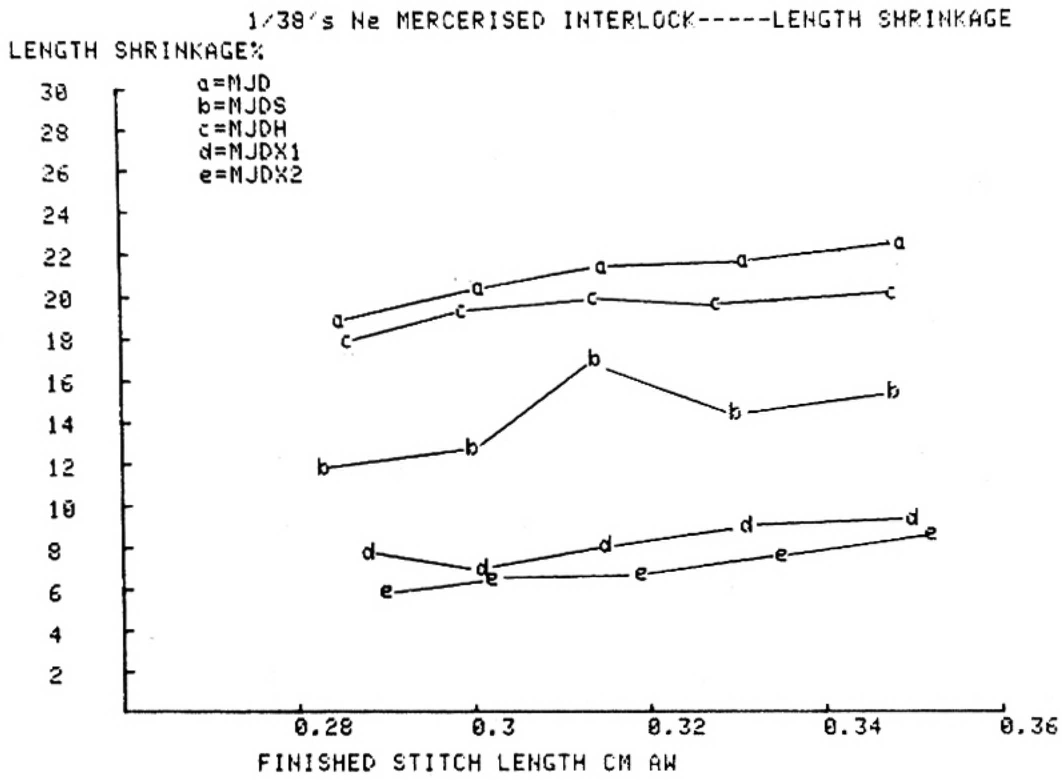

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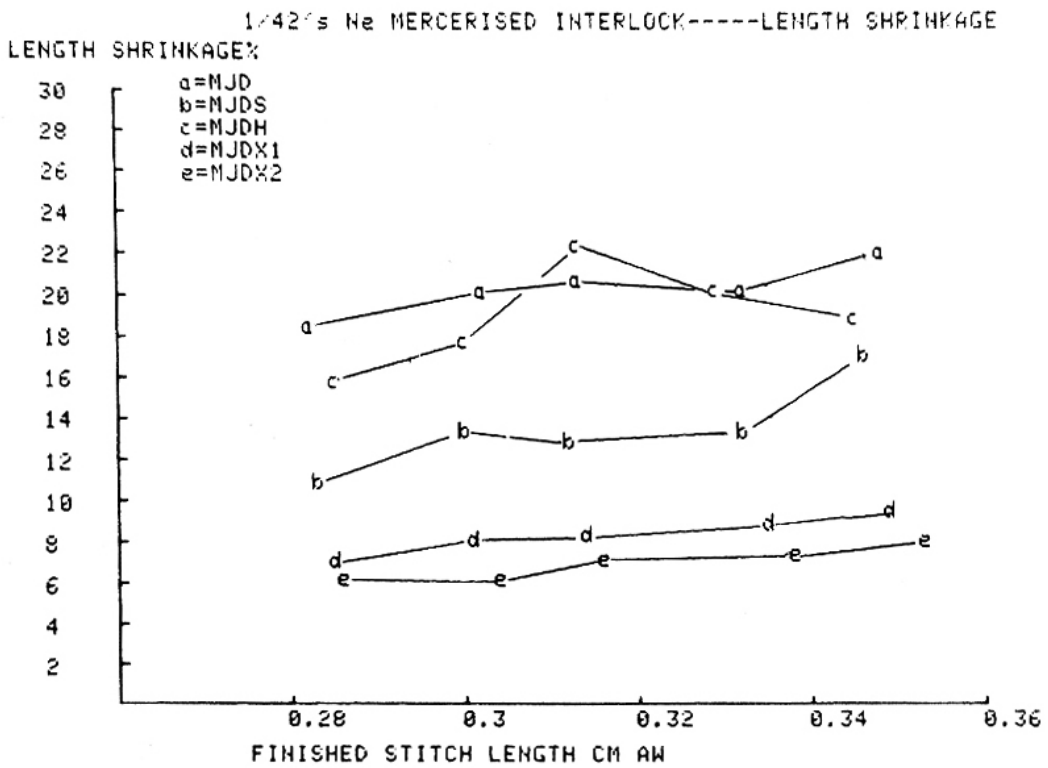

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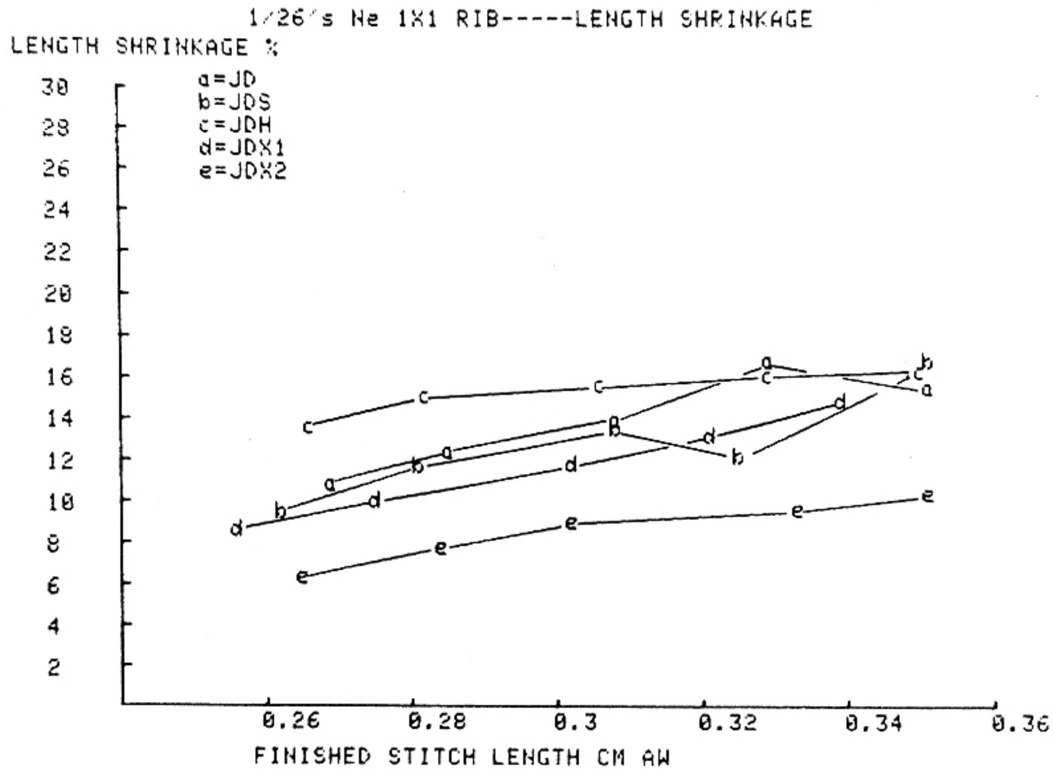

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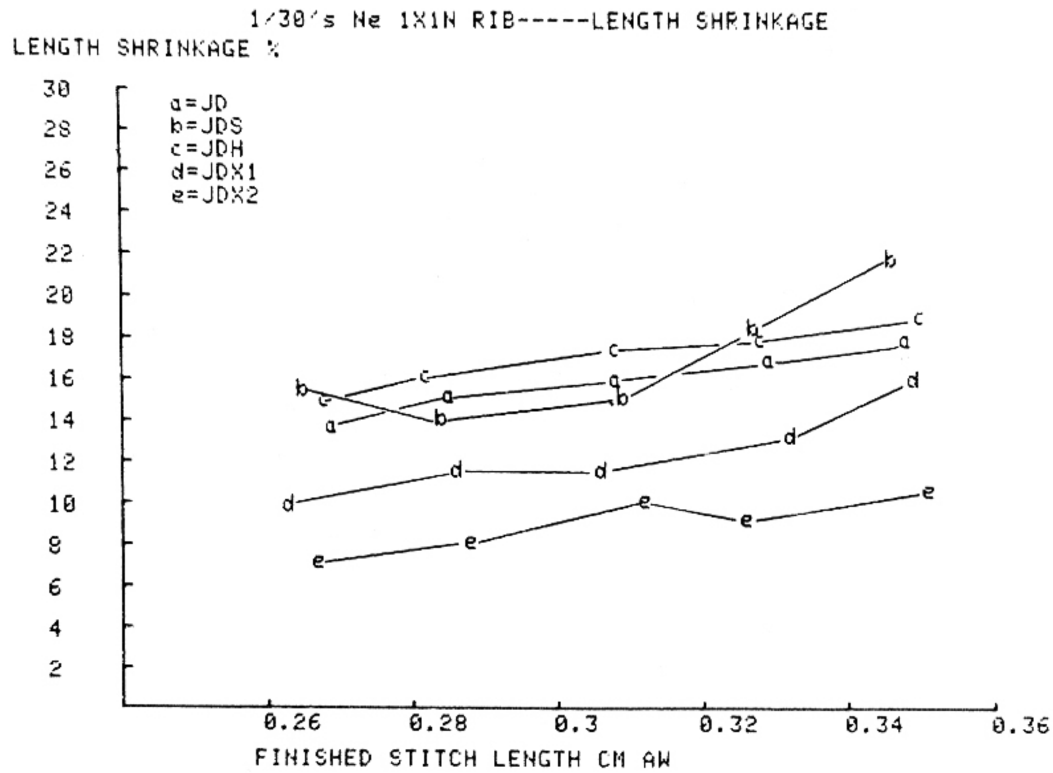

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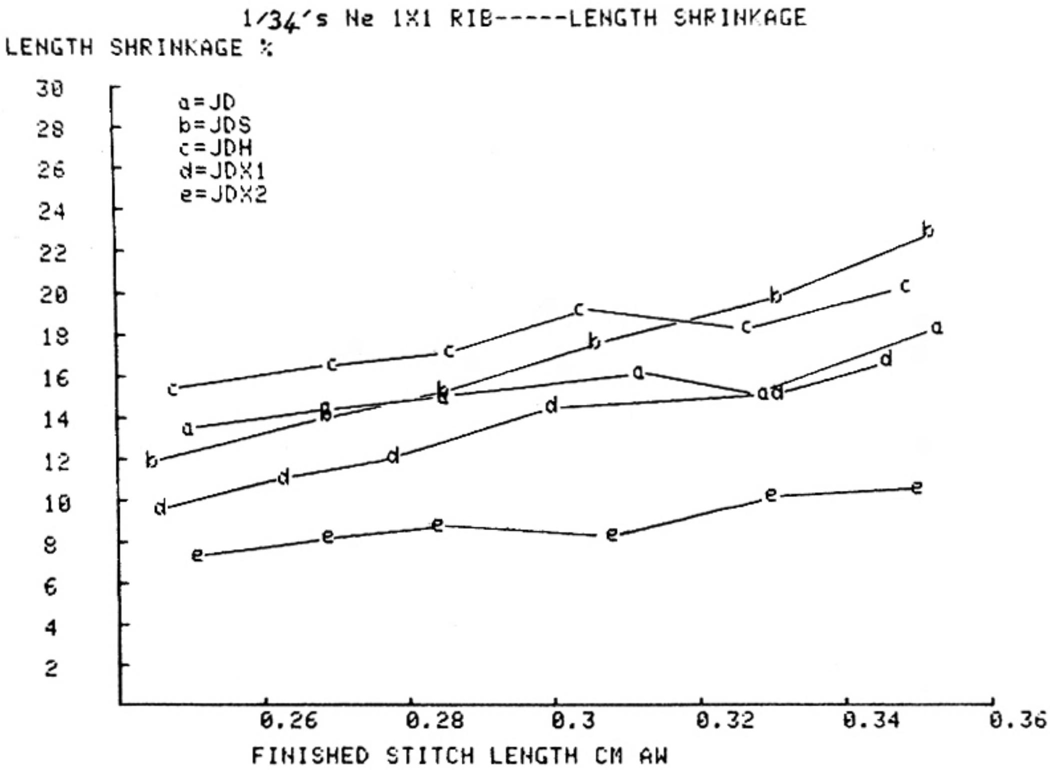

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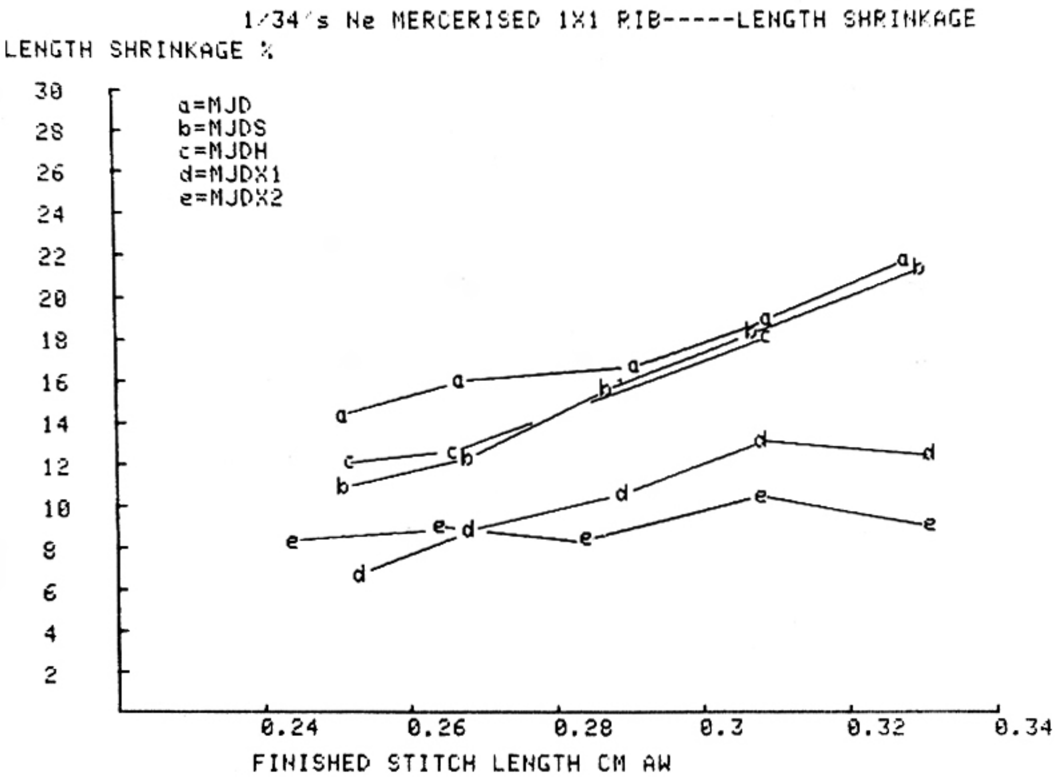

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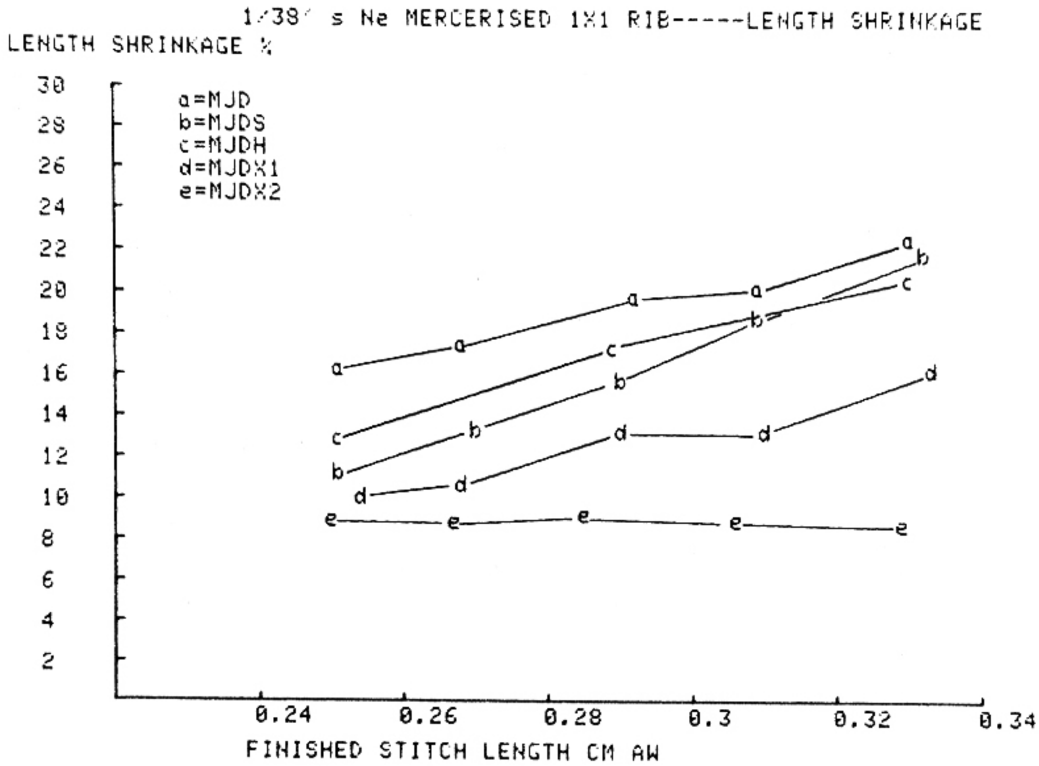

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