Fast Radiographic Systems

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FAST RADIOGRAPHIC SYSTEMS

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Abstract. The following paper is accepted for presentation on 17 October 1984 to the 3rd European Conference on Nondestructive Testing, Florence, Italy, 15-18 October, 1984.

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FAST RADIOGRAPHIC SYSTEMS

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Summary

Industrial radiography can be performed with shorter exposure times, when instead of X-ray film with lead intensifying screens the radiographic paper with fluorescent screen is used. With paper radiography one can obtain lower material, equipment, and labor costs, shorter exposure and processing times, and easier radiation protection. The speed of the radiographic inspection can also be increased by the use of fluorometallic intensifying screens together with a special brand of X-ray film.

Before accepting either of the two fast radiographic systems one must be sure that they can produce radiographs of adequate image quality. Therefore an investigation was performed on that subject using ISO wire IQI's and ASTM penetrameters. The radiographic image quality was tested for aluminium and steel up to 30 mm thick using various brands of radiographic paper and X-ray film with fluorometallic screens and comparing them with fast X-ray films with lead screens.

Both systems give satisfactory results.

*) Work performed under contract with Risø National Laboratory.

1. INTRODUCTION

Radiographic paper, used with fluoroscent intensifying screens, is available for industrial radiography since some time. Its sensitometric properties, radiographic image quality, and practical applications for industrial radiography were already investigated at Risø in 1977. In the first report on that subject [1] review of literature search was given together with the results of an investigation performed on the Kodak Industrex Instant 600 and 610 and Agfa-Gevaert Structurix IC radiographic papers. Later a comparison of X-ray film and paper radiography was done [2,3]. In a paper published in 1980 the results obtained with the Kodak 600 and 620 and Agfa-Gevaert IC papers were described [4]. In the following investigation a new brand of the radiographic paper (Kodak 700) was included [5,6,7].

Radiographic paper can be used not only with fluorescent but also with fluorometallic intensifying screens. This was prooved and reported in [8].

The constant exposure technique, described already in [4] was further investigated in [9] and prooved to be useful for radiographic paper used both with fluorescent as well as fluorometallic screens.

A general description of paper radiography can also be found in [10] whereas in [11] the assessment of the fast radiographic systems (described in this paper) by the constant exposure technique is given. Besides, a comprehensive report (similar to [1]) on paper and film fast radiographic systems is prepared at Risø now.

2. ADVANTAGES OF FAST RADIOGRAPHIC SYSTEMS

The main advantages of using fast radiographic systems are:

- Shorter exposure times due to the higher speed of the system.
- Lower material costs for paper radiography.
- Shorter processing times, especially with automatic processors.
- Lower labor costs due to shorter exposure and processing times.
- Lower equipment costs due to lower kilovoltages in use.
- Easier radiation protection due to lower kilovoltages in use.

3. RADIOGRAPHIC PAPER

The properties of the radiographic paper, intensifying screens used with it and its processing were already described in detail before. It is, perhaps, worth repeating here that at present the following brands of radiographic paper and intensifying screens are available:

- Kodak Industrex Instant 600, Rapid 620 and 700 papers to be used with Kodak Industrex Intensifying Screen F1 (high-speed, high-contrast) and F2 (lower contrast, smaller intensification).
- Agfa-Gevaert Structurix IC paper to be used with fluorescent IC screen Type II or with fluorometallic RCF screen.

Both Kodak as well as Agfa-Gevaert radiographic papers were processed in their respective automatic processors, as described in [1].

4. FAST X-RAY FILMS

Just recently Agfa-Gevaert has put on the market a new, fast X-

ray film. It is the Structurix RCF, a high contrast film, specially designed for use with fluorometallic intensifying screens. This film is sensitive to X- and gamma-rays, UV-, violet and blue rays, and to rays emitted by the fluorometallic screens. The spectral sensitivity of Structurix IC paper, RCF film and screens was reproduced in [8].

Agfa-Gevaert allows the processing of the RCF film in the same manner as all other Structurix films. When using conventional manual processing the G 127 developer (concentration: 1 part of G 127 + 4 parts of water) is to be used for developing at 20°C for 5 min. Rapid processing is also possible and even recommended. For rapid manual processing the G 127 developer in (1 + 1) concentration is to be used at 35°C for 45 s (with continuous agitation). For rapid machine processing the G 127/G 135 developers are to be used at 42°C. As no Structurix automatic machine processors were available in Denmark, some automatic processing of the RCF film was performed using the Rapiline 63 processor, made available for that purpose by the Agfa-Gevaert A/S in Glostrup, Denmark. In this automatic processor the RCF film was developed at 35°C for 32 s in a (1 + 3) concentrated G 137 developer. This automatic processing gave, however, very inconsistent results and therefore was not further used.

Thus the RCF film was normally developed for 5 min at 20°C in the (1 + 4) G 127 developer and for 45 s at 35°C in the (1 + 1) G 127.

For the sake of comparison two brands of the conventional industrial fast X-ray films were used: the Kodak Industrex D and Agfa-Gevaert Structurix D 10. Both were used with 0.05 + 0.10 mm lead intensifying screens (above 50 kV) or without screens (below 50 kV). They were manually processed: The Kodak D film in the DX-80 developer for 4 min at 20°C (1 + 4 concentration) and the Agfa-Gevaert D 10 film for 5 min at 20°C in the G 127 developer (1 + 5 concentration).

5. X-RAY EQUIPMENT

The investigation was performed using a Balteau 50 kV, constant potential (beryllium window X-ray tube) X-ray machine for kilovoltages up to 50 kV and Andrex 180 and 300 kV, selfrectified, X-ray machines, above 50 kV. They were previously described in [1] and other reports.

6. IMAGE QUALITY INDICATORS

Two types of image quality indicators were used: ISO wire IQI's and ASTM penetrameters. The relative merits and disadvantages of using those two systems were discussed in [6,7], whereas in [9] details about the IQS's are given.

7. OBJECTS EXAMINED

Aluminium and steel plates, 10, 20 and 30 mm thick, were radiographed using different film/paper and intensifying screen combinations. For Al plates the 50 kV Balteau and 180 kV Andrex X-ray machines were used, whereas the Fe plates were radiographed with the Andrex 300 kV machine. On each plate a wire IQI and a set of

three ASTM penetrameters was present.

8. RADIOGRAPHIC IMAGE QUALITY

To be able to judge to what extent the fast radiographic systems can be used the radiographic image quality obtained with those systems was tested. For that purpose the described above equipment, indicators and test objects were used.

Each radiograph of an Al or Fe plate, containing the images of the wire IQI and ASTM penetrameters was visually examined by three persons and the results of their assessment were presented in the previously adapted form of diagrams [6,7,8,9], on which the finding of each observer is marked by a black line, whereas the dotted strip signifies that all the three persons were of the same oppinion. The results obtained before were supplemented with those obtained during the present investigation using Agfa-Gevaert D 10 and RCF films and IC paper with fluorometallic screens.

8.1. Kodak fast systems

The results of the investigation performed with Kodak Industrex D film and Industrex Instant 600 and Rapid 620 and 700 papers were already presented in [6,7]. They will be compared below with the results obtained during the present investigation for Agfa-Gevaert film and paper.

8.2. Agfa-Gevaert fast systems

During the present investigation the Agfa-Gevaert Structurix D 10 X-ray film was used. With the Balteau 50 kV X-ray apparatus it was exposed without intensifying screens whereas for the Andrex 180 and 300 kV machines 0.05 + 0.10 mm lead screens were used.

The RCF film was exposed with fluorometallic RCF screens. It was manually developed at 20°C for 5 min in the (1 + 4) concentrated G 127 developer. Similar investigation was performed for the Structurix IC paper exposed with fluorometallic screen, whereas results for the IC paper exposed with fluorescent IC Type II screen were taken from a previous investigation [6,7]. The results are presented on fig. 1 for Al and fig. 2 for Fe.

8.3. Constant exposure technique

The constant exposure technique, described in [4,9], was also used to compare radiographic image quality of fast radiographic systems. The results thereof are presented in [11].

9. COMPARISON OF RESULTS

The comparison will be done separately for Al in the region of low voltage (soft X-rays, up to 50 kV) and intermediate voltage range (50 to 90 kV), whereas the comparison for Fe occured in the region from 125 to 300 kV.

9.1. Aluminium examined with soft X-rays

1) For 10 mm of Al examined at 45 kV wire IQI sentivity of 1.6 % was obtained with all systems (only on the Kodak Industrex D film one more wire-1.25 % - could be seen).

2) A full comparison for 10 mm Al at 50 kV could not be done because for most systems the exposure time was too short to be able to make reliable exposures.

3) For 20 mm Al at 45 kV sensitivity of 1 % was obtained with all systems. Even higher sensitivities (0.8 %) cpould be reached

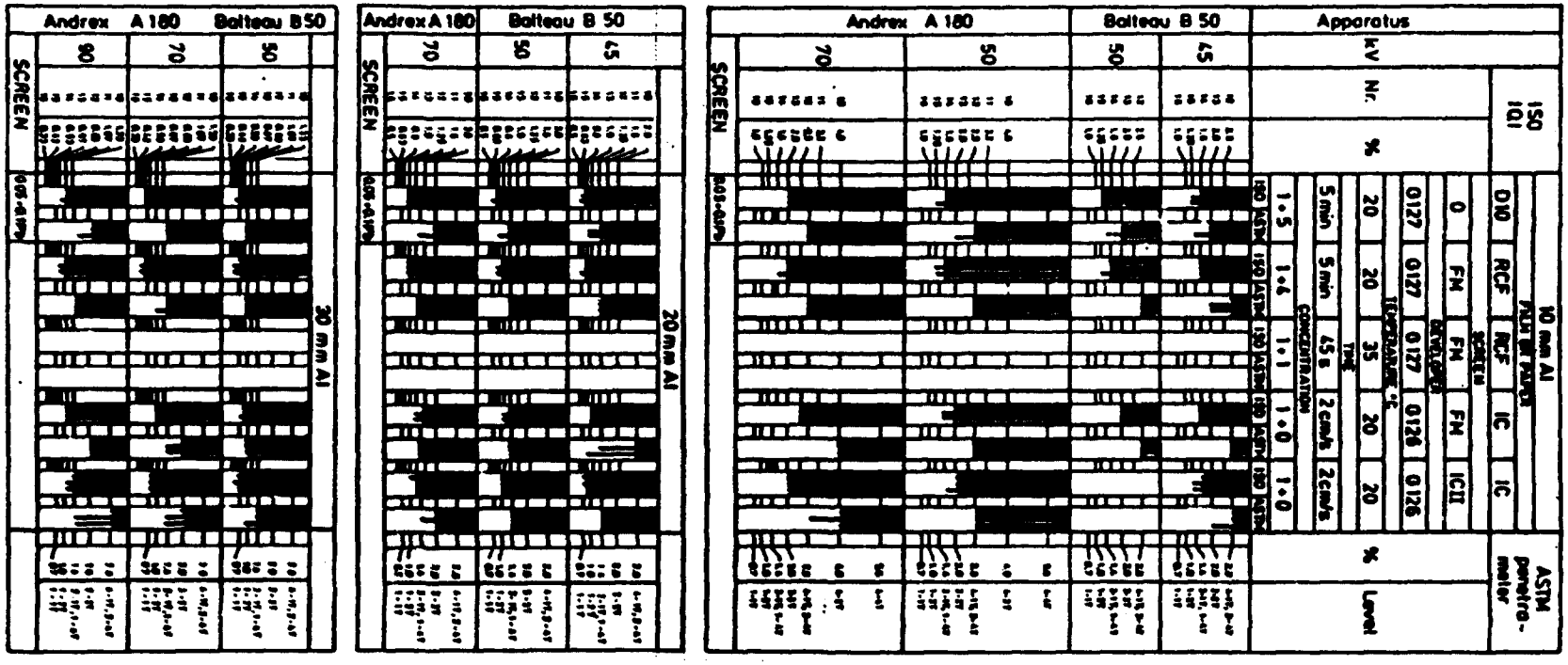

Fig. 1. Radiographic sensitivity of Agfa-Gevaert fast systems for 10, 20 and 30 mm Al

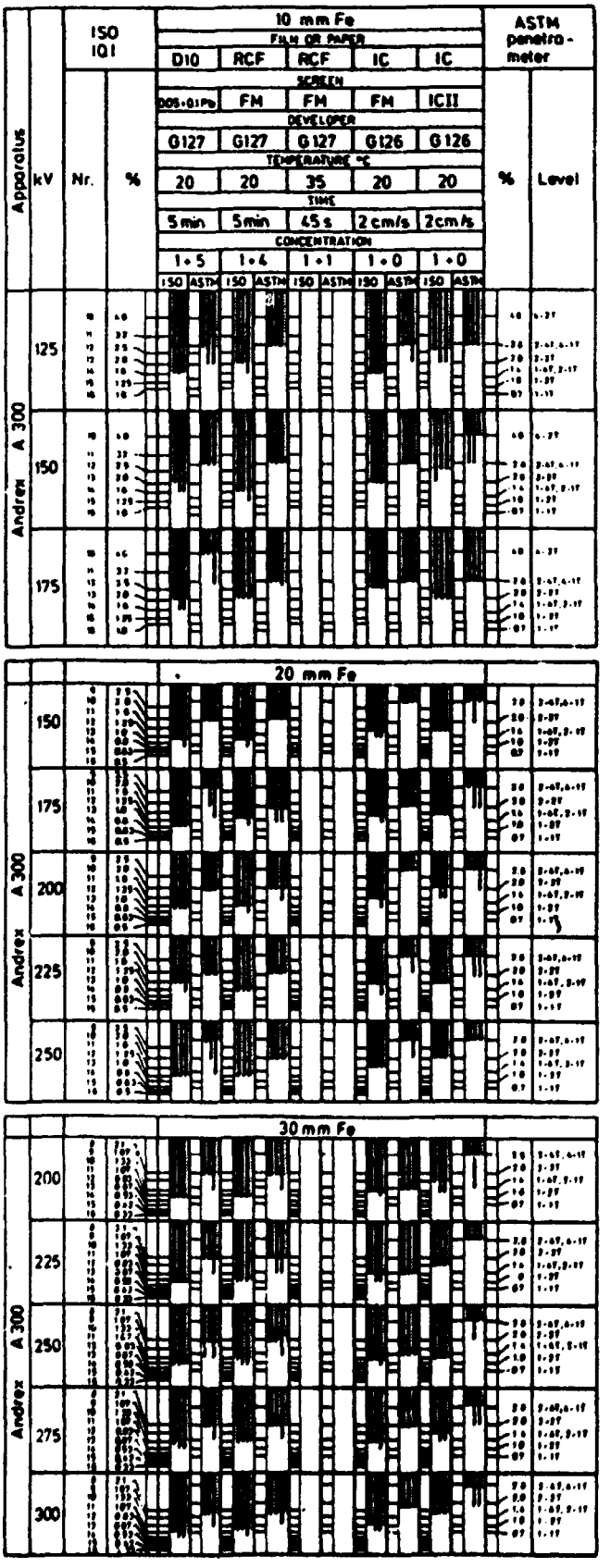

Fig.2. Radiographic sensitivity for Agfa-Gevaert fast systems for 10, 20 and 30 mm Fe

for the D 10 and RCF films as well as the IC paper with IC II screen.

4) For 20 mm Al at 50 kV almost the same results were obtained. Here on the IC paper with FM screen one less wire (1.25 %) and on both D and D 10 films one more wire (0.8 %) were seen.

5) 30 mm Al was examined only at 50 kV. Here a 0.83 % sensitivity was reached for all systems. One wire more (0.67 %) was seen on both films and IC paper with IC II screen.

9.2. Aluminium examined in the intermediate kilovoltage range

1) Results obtained for Al with the single-tank, self-rectified X-ray machine are slightly worse than those with a soft X-ray machine (beryllium window, constant potential).

2) For 10 mm Al at 50 kV a 2 % wire sensitivity was obtained for all systems. More wires could be seen for D (1.25 %), D 10 and RCF (1.6 %) films.

3) The same 2 % sensitivity was reached for 10 mm Al at 70 kV (with the exception of IC paper with FM screen - 2,5 %, and D film - 1.6 %).

4) For 20 mm Al at 70 kV the wire sensitivity of 1.6 % was reached by all systems. Here on all films two more wires (1 %) could be seen.

5) For 30 mm Al at 70 kV all papers showed sensitivities of 1.07 % (IC with IC II even 0.83 %) whereas on all films two more wires (0.67 %) were seen.

6) For the same reasons (as mentioned in 9.1.2) above) full comparison was not possible for 30 mm Al at 90 kV.

9.3. General conclusions for aluminium

1) In the 10 to 30 mm thickness range examined with soft X-rays radiographic wire sensitivity always better than 2 % can be obtained for all systems. It improves from 1.6 % at 10 mm to 1 % at 20 mm and 0.83 % at 30 mm.

2) In the above thickness range usually one more wire can be seen on fast X-ray film.

3) Also when examined with single tank, self-rectified X-ray machines a 2% sensitivity is reached for Al in the 10 to 30 mm thickness range. It improves from 2 % at 10 mm to 1.6 % at 20 mm and 1.07 % at 30 mm. Sometimes even two more wires can be seen on fast films.

4) To obtain best radiographic sensitivity for Al the kilovoltage must be carefully chosen for a given Al thickness and type of film/paper.

9.4. Steel

1) For 10 mm of Fe, with kilovoltages properly chosen (e.g. 150 kV) a 2% sensitivity can be obtained with all systems. One or even two (1.25 %) more wires can sometimes be seen on film or IC paper with FM screen.

2) If the kilovoltage is not to high (more than 200 kV) a sensitivity of 1.6 % can be reached for all systems at 20 mm Fe.

3) Also here one (1.25 %) or even two (1 %) more wires can be seen on fast film.

4) For 30 mm Fe and kilovoltages not exceeding 250 kV wire sensitivities of 1.33 % can be reached for all systems. One (1.07 %) and sometimes even two (0.83 %) more wires can be seen on film.

5) As for Al, in the 10 to 30 mm thickness range, also Fe sensitivities of 2 % are obtainable for all systems. Here the choice of proper kilovoltage is not so critical as for Al.

9.5. Comparison with other X-ray films

The fast paper and film systems mentioned above were compared with conventional fast X-ray films (Kodak Industrex D and Agfa-Gevaert Structurix D 10) used with lead intensifying screens. Radiographic sensitivities of other X-ray films (Kodak C,A,M,DR,SR and Agfa-Gevaert D7,D5,D4,D2) were also compared with those mentioned above. This was done by the constant exposure technique and is presented in [11].

10. PROCESSING

All the conventional X-ray films were manually processed and the radiographic papers were processed in automatic processors according to procedures recommended by their manufacturers.

Different processing modes were tried for the Agfa-Gevaert Structurix RCF film used with FM screens. Both manual as well as automatic processing was tested, using different developing temperatures, time and developer concentration. The influence of the processing mode on the relative speed and kilovoltage is shown on fig. 3.

Agfa-Gevaert Structurix RCF-FM

30 mm Al 10 mm Fe

Mode	Processing	Concentration	170 kV		25 mAmin		
			mAmin	Speed	W	%	
Manual	20°C; 5 min	1+5	0.275	1	88	100	M1
	35°C; 45 s	1+5	0.155	1.77	86.5	98	M2
	20°C; 5 min	1+4	0.22	1.25	82.5	99	M3
	35°C; 45 s	1+4	0.16	1.72	86.25	97	M4
	20°C; 5 min	1+1	0.10	2.75	82.75	94	M5
	35°C; 45 s	1+1	0.135	2.04	84	96	M6
Automat.	35°C; 32 s	1+3	0.22	1.25	82.5	99	A

Mode	Processing	Concentration	215 kV		100 mAmin		
			mAmin	Speed	W	%	
Manual	20°C; 5 min	1+5	0.73	1	114	100	M1
	35°C; 45 s	1+5	0.75	0.97	115	101	M2
	20°C; 5 min	1+4	0.60	1.22	112.5	98	M3
	35°C; 45 s	1+4	0.54	1.35	111.5	98	M4
	20°C; 5 min	1+1	0.54	1.35	112.5	99	M5
	35°C; 45 s	1+1	0.41	1.78	110.75	97	M6
Automat.	35°C; 32 s	1+3	0.86	1.11	113.5	99.5	A

Fig. 3 Different processing modes of the RCF film

As explained above manual processing modes M3 and M6 are recommended by the film manufacturer for the RCF film and are used in the comparison of relative speed and kilovoltage (fig. 3). However, the investigation of the radiographic quality (figs. 1 & 2) was performed using only the processing mode M3, because it was prooved [11] that the results obtained for M3 and M6 were almost identical. Besides, the use of M6, requiring a high concentration of the developer (1 + 1) and relatively high temperature (35°C) was not very practical. As mentioned above the available automatic processor did not give reliable results.

As can be seen (fig. 3) the manual M3 and automatic A processing modes have visible influence on the relative speed of the RCF film whereas the manual mode M6 can increase the speed by about 50 %.

11. CHARACTERISTIC CURVES

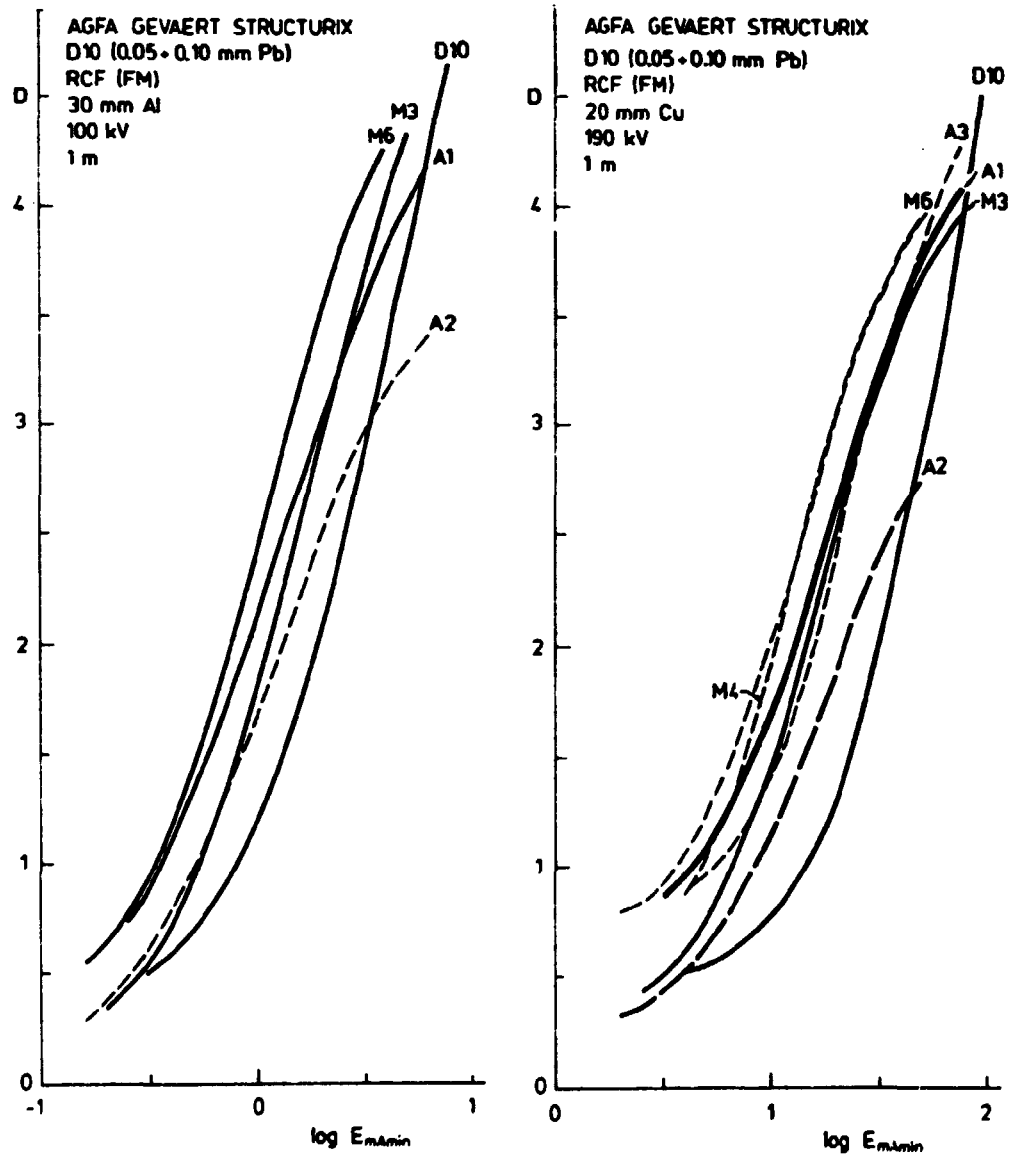

Fig. 4. Characteristic curves for D 10 and RCF films

Characteristic curves for fast Kodak film and paper were previously given in [1,2,3,10] where also curves for Agfa-Gevaert IC paper with IC II screen can be found. For the IC paper with the FM screen characteristic curves were given in [8]. Now curves for Agfa-Gevaert D 10 and RCF film are reproduced on fig. 4.

12. SPEED, CONTRAST AND EXPOSURE LATITUDE

Relative speed, contrast and exposure latitude were previously investigated for different paper and screen combinations and were reported in [1,2,3,4,8,9,10].

The relative speed can be determined from characteristic curves, exposure charts or radiographs performed for the determination of the radiographic quality. The relative speed was calculated for a density of 2.5 for film and 1.0 for paper. For the same radiographic system it depends on the quality of radiation (kilovoltage, filtration, type of X-ray machine). Below relative speed of fast radiographic systems used throughout this investigation will be given for 30 mm Al exposed at 170 kV and 10 mm Fe at 215 kV. Results shown on fig. 5 give also the reduction in kilovoltage possible with the use of a constant exposure (mAmin) technique. The relative speed and kilovoltage decrease are calculated in relation to the slowest system (Kodak SR and Agfa-Gevaert D 2 films).

Kodak Industrex

30 mm Al

Film/paper	Screen	170 kV		25 mAmin	
		mAmin	Speed	kV	%
SR	Pb 0.05+0.10 mm Pb	25	1	170	100
OR		18.75	1.3	160	94
M		6.67	3.7	120	71
A		1.50	17	85	50
C		1.24	20	77	45
D		0.57	44	70	41
700	F2	0.73	34	74	44
600		0.83	30	75	44
620		0.31	81	68	40
700	F1	0.13	192	64	38
600		0.08	313	63	37
620		0.04	625	61	36

10 mm Fe

Film/paper	Screen	215 kV		100 mAmin	
		mAmin	Speed	kV	%
SR	Pb 0.05+0.10 mm Pb	100	1	215	100
OR		80	1.25	190	88
M		30	3.33	165	77
A		7.5	13	135	63
C		6	17	130	61
D		3	33	120	56
700	F2	4.5	22	127	59
600		4.5	22	127	59
620		1.67	60	117	54
700	F1	1.17	85	112	52
600		0.82	122	112	52
620		0.33	303	108	50

Agfa-Gevaert Structurix

30 mm Al

Film/paper	Screen	170 kV		25 mAmin	
		mAmin	Speed	kV	%
D2	Pb 0.05+0.10 mm Pb	25	1	170	100
D4		5.5	4.55	106	62.4
D5		3.6	6.94	94	55.3
D7		1.85	13.5	91	53.5
D10		0.55	45.5	75	44.1
RCF (M3)	FM	0.22	114	67.5	39.7
RCF (M6)		0.135	185	64	37.6
RCF (A)		0.22	114	67.5	39.7
IC		0.17	147	62.5	36.8
IC	IC II	0.139	180	66	38.8

10 mm Fe

Film/paper	Screen	215 kV		100 mAmin	
		mAmin	Speed	kV	%
D2	Pb 0.05+0.10 mm Pb	90	1	210	100
D4		20	4.5	153	73
D5		12.5	7.2	141	67
D7		6.8	13.2	131	62
D10		2.1	43	118	56
RCF (M3)	FM	0.60	150	112.5	54
RCF (M6)		0.41	220	110.75	53
RCF (A)		0.86	136	113.5	54
IC		0.56	161	110	52
IC	IC II	0.66	136	112	53

Fig. 5. Relative speed and kilovoltage

From the characteristic curves contrast was calculated and reported in 1,2,3,4,8,10 where also exposure latitude was quoted. For the Agfa-Gevaert D 10 and RCF films contrast at film density 2.5 has the following values: D 10 at 30 mm Al/100 kV - 3.95. 20 mm Cu/190 kV - 4.75. RCF (M3): 30 mm Al/100 kV - 4.00. 20 mm Cu/190 kV - 3.90. RCF (M6): 30 mm Al/100 kV - 3.75. 20 mm Cu/190 kV - 3.45. RCF (A): 30 mm Al/100 kV - 3.25. 20 mm Cu/190 kV - 4.4.

13. CONCLUSIONS

13.1. Radiographic quality

1) Best radiographic image quality can be obtained when fast radiographic systems are used with soft X-rays for the examination of light materials (e.g. Al). Even at higher kilovoltages and self-rectified, single-tank X-ray machines a 2 % wire sensitivity can be reached for all fast systems. As usual, the percent wire sensitivity is better for thicker objects.

2) For steel (up to 30 mm) a wire sensitivity of 2 % is shown for all fast systems and improves with the increasing thickness.

3) On fast radiographic film usually one more wire can be detected than on paper.

13.2. Relative speed

1) When used with high speed intensifying screen (Kodak F1, Agfa-Gevaert IC Type II and FM) all radiographic papers and RCF film show greater relative speed than fast X-ray films with lead intensifying screens. One can easily increase the speed of radiographic examination 5 times by choosing a proper combination of paper/film and screen.

2) With the RCF film used with FM screens considerable gain of speed can be reached when using concentrated developer at higher temperature. But even with manual processing at 20°C an increase of speed of about 3 is possible.

13.3. Contrast

1) Best contrast is shown by the fast X-ray film used with lead intensifying screens.

2) For X-ray films used with lead intensifying screens contrast increases with increasing film density, whereas for all other fast systems the contrast reaches a maximum.

3) Contrast is always lower for the radiographic paper than for X-ray film. The use of FM screens can improve contrast.

4) The processing mode of the RCF film has little influence on the contrast.

13.4. General conclusions

1) One can profit by all the advantages of fast radiographic systems (as mentioned at the beginning) and at the same time have adequate radiographic image quality (better than 2 % wire sensitivity).

2) Fast radiographic systems can be especially recommended for use with soft X-rays, light weight materials (e.g. light metals) and steel not thicker than about 30 mm.

3) One can hope that better knowledge of the intrinsic properties of the fast systems will contribute to their wider use in many fields of radiographic control performed up till now by the use of conventional X-ray films.

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FAST RADIOGRAPHIC SYSTEMS

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ATLAS ADVANCED ENGINEERING DIVISION x)

Date August 1984

Department or group

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15 pages + tables + 5 illustrations

Abstract

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Before accepting either of the two fast radiographic systems one must be sure that they can produce radiographs of adequate image quality. Therefore an investigation was performed on that subject using ISO wire IQI's and ASTM penetrameters. The radiographic image quality was tested for aluminium and steel up to 30 mm thick using various brands of radiographic paper and X-ray film with fluorometallic screens and comparing them with fast X-ray films with lead screens.

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