The Analysis and Correction of Factors Influencing Imaging Quality of Digital Radiographic Testing System

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Abstract: -The factors influencing imaging quality of industrial digital radiographic imaging system are analyzed detailedly. This imaging system is a new type industrial digital radiographic imaging system developed by author, The structure of ray conversion screen and its non-uniformity, the discordance analysis of scientific grade CCD and vignetting effect of the optical system are introduced**. T**he correction method of non-uniformity for testing system is studied, the correction arithmetic is given and the methods of reducing circuit random noise and the noise produced by scatter ray are illuminated. The correction image and the one that don't be corrected are given, the merits of this system and problem need to be more studied are illuminated.

Key-Words: - digital radiographic imaging, non-uniformity correction, x ray conversion, scientific grade CCD, dark current

1. Based on scientific grade CCD camera imaging of the new industrial Radiographic Testing System Introduction

In the field of Radiographic NDT, despite the large number of film imaging is still in use but with the development of non-film imaging ,it becomes a trends in radiographic testing therewith real-time detection of the highly efficient, no supplies caused by low-cost, in particular the exchangeable and the characteristics of convenience storage. At present, applications and more research is based on the image intensifier and CCD camera or flat panel detector compose digital imaging system. This two main systems is more used in low energy X-ray source (450 kV) to compose testing systems, the first imaging systems has a poor imaging quality and ask for high requirements of X-ray source , the last one has high price.

In order to resolve the problem of under large and medium sized component's high-energy X-ray (greater than 1 MeV) digital imaging as well as to provide a more universal, lower prices , high-performance digital imaging systems for industry, whit support of national defense project, a new type of opening digital radiographic imaging system developed by the author, which is based on single-crystal scintillation conversion screen, scientific grade CCD camera-found refrigeration, the system components as shown in Figure 1. Outside countries use the way of direct coupling ray-cone to industrial CCD camera [2]. The function of conversion screen is hold the ray distribution that permeated workpiece transform to visible light images which carry the work piece's internal information, the purpose of 45 °reflector is reflecting the visible light images to the CCD camera, and the residual ray through the conversion screen can straight drill through the reflector so that they can not shoot into the camera, to avoid the damage to camera and the image noise by ray (This point has been proven by experiments). Because of the image after transforms is shimmer image, adopt the scientific grade CCD camera-found refrigeration,which has big dynamice range, small noise, many element and good uniform ,to gain image for long exposal time, namely slow scan imaging, this method similar to film imaging (time short), compares with the fast imaging system, may greatly reduce the image noise by radial fluctuation and electronic enhancement. Moreover this system can be used in X-ray of low energy or high energy and γ -ray, extend the apply scope, at present it is a single system that suits the high energy to area array imaging it also has

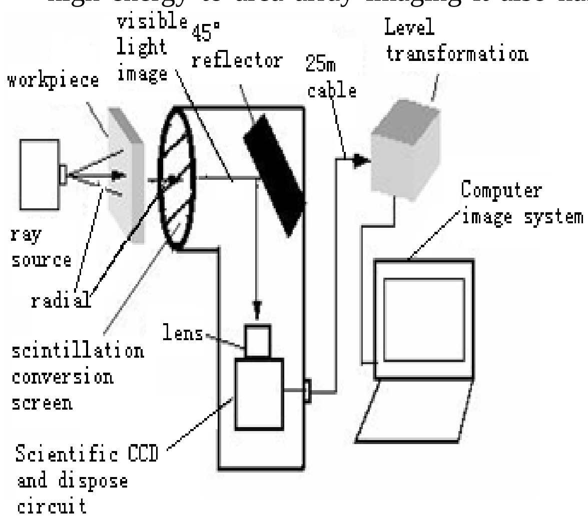


Fig.1 Compose of digital Radiographic testing system

strongpoint of low price and high testing level, its shortcoming is imaging time is long compared to above two kinds, could not carry through real-time imaging to the movement work piece.

2. The analysis of System non-uniformity

After the system develops successfully, through the experiments may know, the primitive imaging's quality of this system is not very high, the uniformity steel plate image as shown in Figure 2, actually appears high and low frequency noise from the originally image which should be uniformity gray scale,. After anatomize and a lot of experiments, we thought it mainly has following several factors.

2.1 Nonuniformity of ray source intensity distributing

This point is recognized. Namely the ray source output beam is taper , the central intensity is big, around intensity is small, for the fixed ray source, its distribution is fixed, therefore it can be adjusted, its displays is nonuniformity of low frequency, causes the center image brightness to be higher than around brightness, influencing degree concerns with the ray source and the imaging

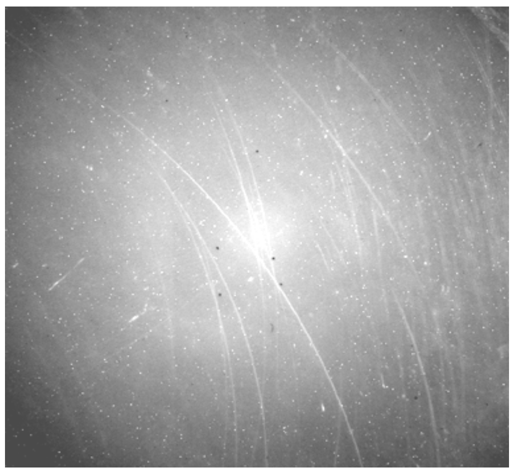


Fig.2 Uniformity steel plate image

geometry condition.

2.2 Nonuniformity of ray conversion screen

2.2.1 The structure of ray conversion screen

Through advisement and research of the ray conversion screen's factors, conversion screen used CSI (Tl) scintillation crystal, the structure of design is shown in Figure 3. Because CSI (Tl) scintillation crystal is soft and easy deliquescence, must be sealed up, using black aluminum casing which can absorb ray to protect and fixed the entire conversion screen for the images clear, optical glass protects the crystal, the oil layer in addition to airproof, but also for the role of matching refractive index to reduce the reflection from different media interfaces, so that more light can forward transmit, anti-reflect film can add thoroughly penetrated, reduce the reflection of optical glass - air interface and increase light output.

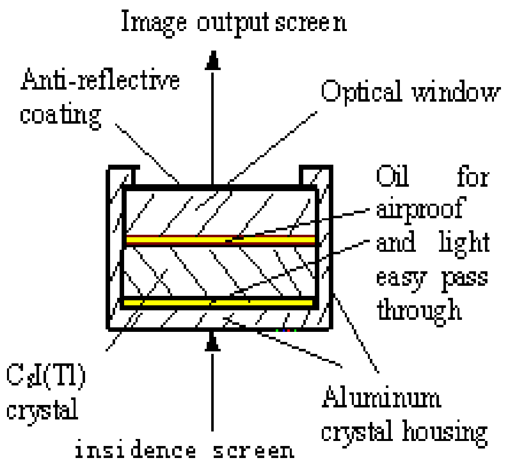


Fig.3 Structure of conversion screen

2.2.2 The non-uniformity analysis of ray conversion screen

Ray conversion screen consign Russia to develop, which is a key components of imaging ,through a large amount of research, experiment and analysis that we know its imaging characteristics bear on technology and ray hardness, but the nonuniformity is inherent ,what is called nonuniformit is different position of ray conversion screen respond efficiency's otherness on the same intensity of ray. Figure 2 showing a bright spot (or dark spot) and linear bright line (or dark line), which is due to the defects of manufacturing process and technology of screen ,the different screen's flaw is different, but its position is fixed. Therefore, as long as the screen and CCD relative position is fixed, it can be considered the defects is fixed, therefore it can be corrected.

2. 3 Vignetting effect of the optical system

Optical system mostly includes 45 °reflector and lens. As the larger reflector designed, its inserted optical path will not increase vignetting of field lens. As we all know, it is impossible that field lens aperture to be very big, that caused vignetting effects, that is, if the surface brightness is uniformity, the imaging back axis' is greatest brightness, the more apart from axis region the lower imaging brightness, this phenomenon of middle is bright , gradually become dark was called "ray faint" or "vignetting", which is the basic knowledge of geometric optical imaging, the camera lens's parameter is the main decision. Its effect on ray imaging is the same as the situation of 2.1's taper ray, so that the phenomenon of middle is bright then edge become dark is comprehensive results of both aspect ,it may be solved by increasing aperture lens to reduce vignetting (at the same time shortened imaging time), so that generally choose larger aperture's lens.

2.4 The non-uniformity analysis of scientific grade CCD

In order to economize cost and satisfy the request to deliver a picture in a long line in the radiographic testing, the scientific grade

CCD of this system is developed by the author based on purchasing the scientific grade CCD, but it is universal.

2.4.1 Performance of CCD

The designed camera is used for changing X-ray faint smooth picture outputted into the digital picture. According to the general requirement and the situation of investigating, we select the ISD017AP science grades of CCD, the CCD has semi-conductor refrigeration device and Pt electric resistance which is used for measuring temperature. The pin of ISD017AP is shown in Fig.4. Main characteristic: (1)Effective picture element: 1040 x 1160; (2) Size of picture element： 16μm×16μm; (3)Large dynamic range; (4)Low dark current; (5) The range of the spectrum responding is wide; (6)Axial symmetry structure; (7)High sensitive degree of ultraviolet ray; (8)There is no effect of emission of light. (9)The output register has 1094 pels (horizontal register, 1040 of them are effective, there are 27 empty registers in both ends of the register). The light electricity parameter of CCD is showed in Table1.

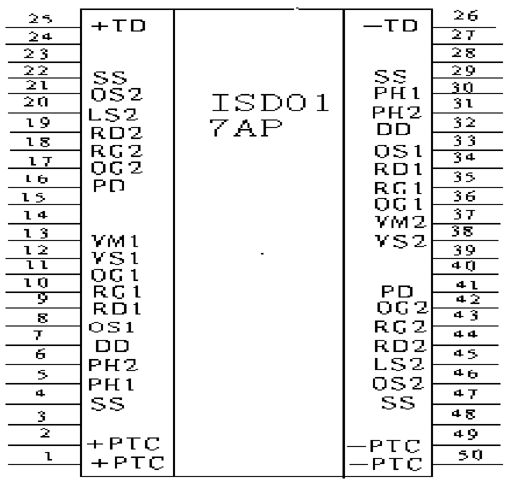


Fig.4 Pin of ISD017AP

The require of walking and shifting time sequence is showed in Fig.5. VM2 run 1/2 pulse width before VM1 (VS1 the same as

Table 1 The main performance parameter of ISD017AP CCD

Parameter	unit	min	typ.	Max.
Saturation signal	V	0.4	0.7	
Full well	Ke^-		130	
Optical response non-uniformity	%		1.5	2.5
Dark signa	e^-/s		20	
Charge transfer inefficiency			1×10^{-5}	3×10^{-5}
Readout noise	e^-		10	15
Quantum efficiency 250nm	%		20	
400nm	%		35	
700nm	%		55	
1000nm	%		8	

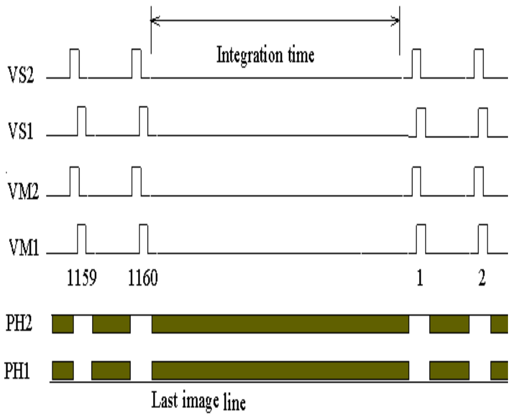


Fig.5 Clock diagram of row transfer for full frame operation

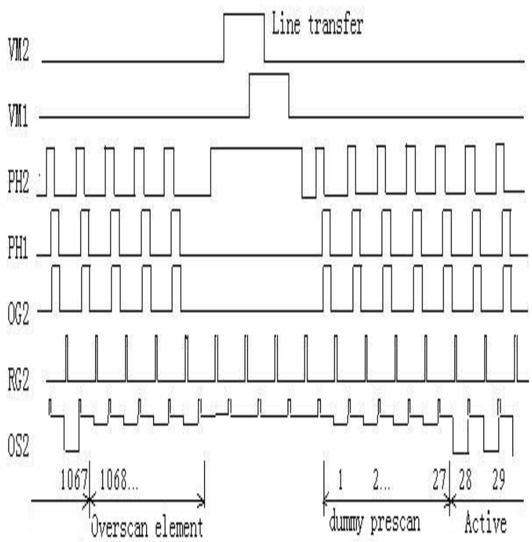


Fig 6 Horizontal transfer Time sequence of CCD Two-stage preamps mode

VM1, VS2 the same as VM2), during the walking and shifting , PH2 is high, PH1 is low. VM1 and VM2 are both low level when the light is accumulated , it has no restrictio on PH1, PH2 level. After accumulating , transfer one line to the horizontal register under the function of VM1 and VM2； under the function of PH1 , PH2 , OG2 and RG2 , one bit with one bit outputs when transfer one. As Fig.6 shows ,it is the require of location shift time sequence . PH2 is leading half pulse width than PH1 , OG2 is the same as PH1. It can be reseted from reading at this time to next time. So pulse of RG2 can be chosed according to the actual conditions in actual applying(the pulse of reseting is not essential during the walking and shifting). Require of the width and level of each signal and the detailed materials can be seen in the list of references

. 2.4.2 Reset Noise Elimination In Signal Preconditioning

The charge collected by CCD convert voltage signal by output circuit under the function of drive

clock, ISD017AP model CCD uses float-install diffuse amplifier (FDA) output. Output signal U pass through pretreatment circuit as Fig.7 to exchange input signal U_O of A/D conversion .time sequence picture is Fig.8.

The work elements is: it outputs signal U at t1 and comes by low noise amplifier A1,

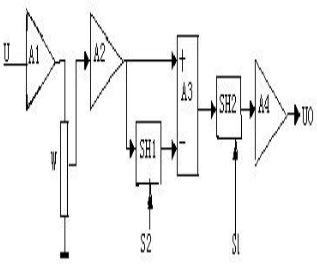


Fig.7 Signal preprocessing circuit of CCD

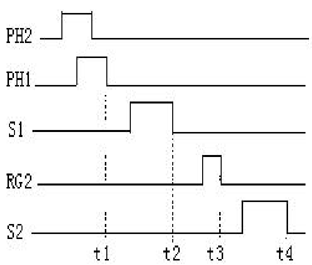


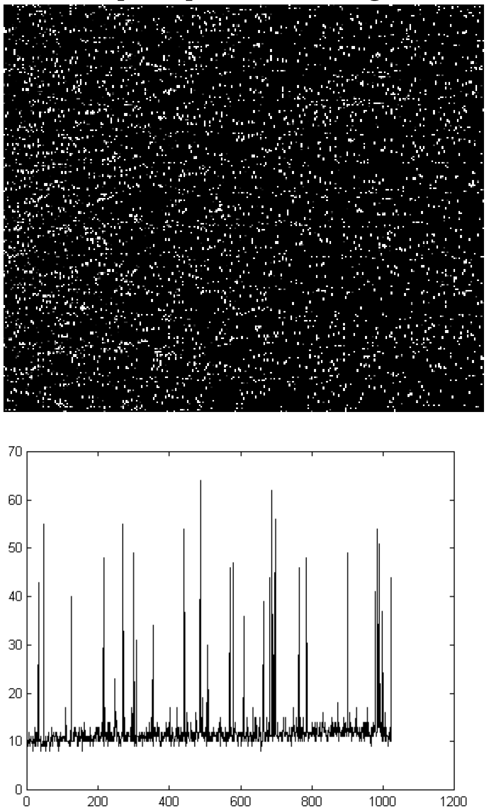
Fig.8 Time sequence of driving preprocessing

potentiometer W and A2 amplifier, in the A3 amplifier this signal subtract reset signal of last time(SH1 is sample keep ware, here keeping signal is the last time reset signal) .Input end at t2 which is kept from sampling keep-ware SH2 and magnified by A4 ,and then export to the A/D conversion, it can keep straight sampling end at next time. A3 is differential amplifier, it realizes this signal subtracting the last reset signal to eliminate reset noise .at t3 this output amplifier will reset with RG, then it is kept from SH1 with S2 at t4, in order to subtract next output.

2.4.3 The non-uniformity of CCD dark current

Because this system need more time to expose (usually ten seconds more), the plain video camera is not used, since the effect of CCD dark current must be considered. The CCD dark current refers to the dark signal formed by current carrier, which is produced after a certain time integral calculus under the situation that has no light to shine on. The dark current is produced by the device on itself, the size of which has a sincere relationship with the temperature of CCD chip, so this kind of camera all begin to work when it is cooled to the temperature of -20℃ to-70℃.

From the influence of imaging quality, the main point that need concern is the discordance of CCD dark current, namely the discordance of electric charge developed by each pixel in the same integral time. The limitation of CCD manufacture technology make each pixel characteristic different. From theories and fulfillment[2] ,we can learn that the discordance of electric charge embody as the characteristic of “Fix peak noise ” , namely that dark current of some pixels is specially big and the difference of mostly pixels is slight, which appears as ”white spot” noise (namely high frequency noise), as shown in figure 9, it is the dark current image after multi frame superimposition average (the aim of superimpose and average is to reduce random noise sharply).By means of the analysis of theories and experiments, we can learn that the discordance of dark current is fixed (can not be reduced or eliminated through multi frame superimposition).So it is also can be corrected.



(a) Average image of 16 frames

(b) Gray scale curves of 300th line

Fig.9 Dark signal Average image of CCD

2.4.4 The analysis of light response non-uniformity of CCD pixel

(1) The concept of light response discordance of pixel

The light response discordance of pixel refers to the degree of irregularity to response sensitivity of each pixel under even illumination. The control response of the scientific grade CCD is conflicting on the craft, but in the high precision imaging, the grey relief caused by this discordance may surpass the useful information relief so as to cover the useful information. It is the main index of CCD, the cause of the discordance is CCD manufacture technology, which embody as the proportion discordance and invariability of the response among each pixel, which is innate of CCD. The general concept is that: under even illumination, when the average output voltage equals to the half of saturation voltage, the discordance can be judged by the following formula[3] :

$$\gamma_{nu}(\%) = \frac{V_{\max}(orV_{\min}) - \frac{1}{n}\sum_{i=1}^{n} V_i}{\frac{1}{n}\sum_{i=1}^{n} V_i} \times 100\% = \pm \frac{\Delta V}{\overline{V}} \times 100\% \qquad (1)$$

Among it, n is the number of effective pixel, V_i is the output voltage corresponded to the i pixel, $\overline{V}$ is the arithmetic mean value of the output voltage of n pixel(namely all of pixels),usually the bigger one between V_{max} and V_{min} absolute value is taken to calculate, so as to show the biggest discordance of this device.

(2) Character and phenomenon of discordance

In view of principle, this discordance is fixed and embody as high and low frequency noise, namely because of technics, some piece of response is low or high, even the response of some pixel is high or low , such dose experiment certificate.

2.5 The noise influence of CCD caused by random noise and scatter ray.

2.5.1 Random noise

The random noise of image in this system is mainly caused by the random noise of circuit, which includes CCD numerated circuit, signal processing circuit, A/D switched circuit and so on. This noise is random and can be reduced through multi-frame superimposition.

2.5.2 The influence of CCD caused by scatter ray.

Though the system adopts 45°reflector and give CCD camera the safeguard of ray shielding, unavoidably some scatter ray will directly illuminate CCD. By means of the analysis of theories and experiments[4], we can learn that this will result in “ white spot ” random noise and affect badly, even will damage CCD. This noise is not regular and very harmful, so we still manage to do it from the structure of the system and shielding.

3 The study of system non-uniformity correction

From the above study, we can learn that plenty of factors which result in system non-uniformity as showing on the image are fixed and regular characteristic, so we can go along software correction by means of image processing.

3.1 Correction measure

The image is meant with matrix form, seen from mathematics angle, the dark current is additive and others are multipled. There are some reasons resulting in the discordance of one pair of image, mainly including random noise, discordance of CCD dark current and light response, lens vignetting, discordance of screen, discordance of ray distribution of ray source.. Except the first kind, the others have fixed characteristic and can get correct matrix aimed at fixed system through experimenting, then by means of software correction reduce the discordant noise. It is necessary to study the correction measure and sequence problem.

3.1.1 Considering random noise first

The noise caused by scatter ray is very harmful, we think a way in the structure and shield as far as possible(in the direction to ray, using little scatter materials, such as aluminum, nonmental matters as far as possible, the reflector holding near the conversion, lengthening the distance between ray source and CCD, increasing the thickness of lead pig shielding CCD and some other measures),it can not be corrected with software, in the following correction ,we think the scatter noise is already nonexistent. We adopt multi frame superimposing average to reduce random noise in circuit, so whether to seek correct matrix of dark current or to get others, we should get it under the circumstance of reducing the random noise in circuit as far as possible.

3.1.2 Correct the non-uniformity of CCD dark current

Each image includes dark current image, dark current is irrelevant to lens, screen, ray source, so we should correct dark current first. The image matrix which is got through superimposing and averaging multi frame of dark current image (covering lens) at the same time divided by exposure time can be thought that it is correct matrix of dark current in unit time , recording for the matrix M. Under the illumination, the image got in t time subtracts $M \cdot t$, then get the image of dark current after correcting.

3.1.3 Correct matrix of the no uniformity of CCD light response

While obtaining the no uniformity of CCD light response, there can't be the influence of lens, screen and ray source (the dark electric current influence is an affirmation to have), so we throw away the lens and get N pairs of image to average with the even light, then carry on dark current to get Q(i, j) after correcting and normalizating to get correct matrix of no uniformity of light response

$$H(i,j) = \frac{Q_l(i,j)}{\overline{Q_l}} \qquad (2)$$

In the formula, $\overline{Q_l}$ is the average of the image Q(i, j) (the average grey level of each pixel), using H to represent the correct matrix of no uniformity of light response.

3.1.4 Three other factor corrects merge

Lens vignetting is relevant to the distance of screen, the no uniformity of screen has a certain relationship with ray energy (hardness), the no uniformity caused by ray source is all relevant to the relative position between ray source and screen and ray source of itself, when the system is confirmed (notice that the system don't include the detected device), the influence and correlation among the three factors are also confirmed. For the sake of simple and having general purpose, we can get correct matrix of three factors merger after the system is confirmed. Confirmed system(the energy of ray source can be adjusted to get close to the examined data physically),obtaining N pairs of image, we should get the average image P_1 after superimposed and then go along the correction of no uniformity between CCD dark current and light response, obtaining the image $P_2=(P_1-M\cdot t)\times 1/H$, supposed P_2 is an n×m matrix, the average value of each pixel is:

$$a=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m}P_{ij}}{n\times m} \qquad (3)$$

In the formula, P_{ij} is the (i, j) pixel value of P_2,so the correct matrix of three factors merger is $E=P_2/a$。

3.2 Result of system correction and experiments

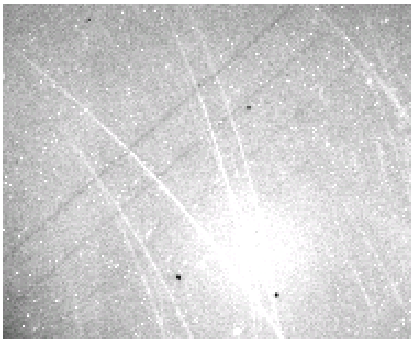
3.2.1 Sequence of system correction and synthetic correct formula

From the above study: when obtaining correct matrix, except dark current is additive, others is multipled. Firstly before the system is built up, to obtain the correct matrix of CCD dark current M and then obtain the correct matrix of no uniformity of light response H, the factors caused by lens, screen, ray source obtain multi image(such as 16 pairs) to calculate and then get merger of correct matrix E ,such is simple and practical. Against to a picture A which is arbitrarily obtained and exposing time as t, after comprehensive correct, the image A^* is:

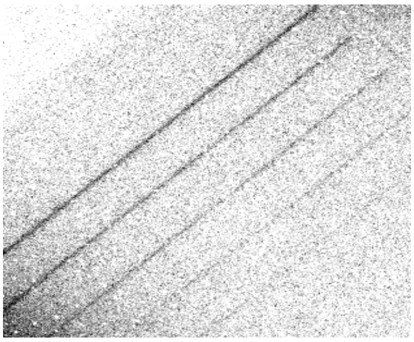
$$A^*=(A-M\cdot t)\times(1/H)\times(1/E) \qquad (4)$$

3.2.2 Experiment result

Adopting the above measures, we carry on a great deal of experiment towards using 3005 national portable X ray source and the examination system composed by the formatter studied by the author, and then obtain every correct matrix. In order to verify the effect of correct measure, we take the image of the third pentameter on 15mm even steel plate. Figure 10 is correct to contrast figure before and after correction, we can see obviously that the no uniformity of the image has reduced sharply after correcting, the number of pentameter we can see also increase before correcting and the quality of image gets an obvious improvement.



(a) Before correction



(b) After correction

Fig.10 The before and after correction image of IQI on steel plate

4 Conclusion

Proved by experiment, ray energy changes in a certain range impact of calibration matrix E very little ,it can be similar to remain the same. Different ray sources, conversion screen, lens and so on, or geometry relations changed, require to re-obtain correction matrix E. By the scientific grade CCD camera and single crystal conversion screen developed ray imaging system has many advantages (particularly available in the portable X-ray source imaging and under high-energy accelerator imaging), through the way of correct its imaging quality is better than the system composed by the image intensifier , the spatial resolution of the system developed author is greater than 3.5lp/mm, the penetrate sensitivity is better than 1.5% ,for the high-precision NDT to static components. Large-scale changes in energy-ray should be further studied of calibration matrix E's mutative orderliness and speed up the imaging time.

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