

(43) International Publication Date
2 October 2014 (02.10.2014)

(51) International Patent Classification: Not classified

(21) International Application Number:
PCT/IB2014/000449(22) International Filing Date:
28 March 2014 (28.03.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2013-074837 29 March 2013 (29.03.2013) JP

(71) Applicant: TOYOTA JIDOSHA KABUSHIKI KAISHA [JP/JP]; 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP).

(72) Inventors: UCHIDA, Keisuke; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP). FURUKAWA, Massashi; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP). KOBAYASHI, Hiroomi; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP). KAWAKITA, Atsushi; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP). OGURA, shuhei; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP). KISHI, Hiroaki; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP).

AKAMATSU, Eiji; c/o KABUSHIKI KAISHA YASKAWA DENKI, of 2-1, Kurosaki-shiroishi, Yahatanishi-ku, Kitakyushu-shi, Fukuoka, 806-0004 (JP). IWAMOTO, Yuta; c/o TOYOTA JIDOSHA KABUSHIKI KAISHA, of 1, Toyota-cho, Toyota-shi, Aichi-ken 471-8571 (JP).

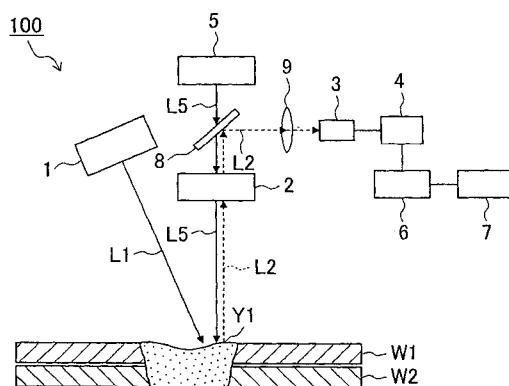
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: WELDED PORTION INSPECTION APPARATUS AND INSPECTION METHOD THEREOF

FIG. 1



(57) Abstract: A welding laser beam (L1) is radiated along welding loci (C11, C12) set in workpieces (W1, W2), or an inspection laser beam (L5) is radiated along scanning loci (C51, C52) set in a molten pool (Y1) of the workpieces that are molten by radiation of the welding laser beam, a returned light beam (L2) including reflection light from the molten pool, vapor light caused due to melting and evaporation of the workpieces, and thermal radiation light emitted from the molten pool is received, and a welding state of a welded portion of the workpieces is inspected based on an intensity of a returned light beam received in a first region inside the molten pool which is relatively close to a given point and an intensity of a returned light beam received in a second region inside the molten pool which is relatively spaced from the given point.



Published:

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WELDED PORTION INSPECTION APPARATUS AND INSPECTION METHOD
THEREOF

BACKGROUND OF THE INVENTION

5

1. Field of the Invention

[0001] The present invention relates to a welded portion inspection apparatus and an inspection method thereof, and relates to an inspection apparatus that inspects a welding state of a welded portion formed at the time when a plurality of workpieces is welded by a laser beam, for example, and an inspection method thereof.

10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 9999

[0004] According to the laser beam welding quality determination system

described in JP 2008-87056 A, the laser reflection light and the welding light are received simultaneously in two predetermined directions different from each other and their respective light receiving signal intensities are compared with a threshold set appropriately. Hereby, it is possible to determine occurrence of any one of the following various types of poor welding: weld shrinkage (underfill) in which a weld bead hollows to bury a gap between steel sheets; unjoined weld in which upper and lower steel sheets are not joined due to an excessively large gap between the steel sheets; depressed weld in which a bead is depressed similarly due to an excessively large gap between steel sheets; and molten weld in which a bead disappears accidentally due to fluctuation of a thermal balance; and holed weld.

[0005] However, in the laser beam welding quality determination system described in JP 2008-87056 A, in a case where the laser torch is apart from workpieces (steel sheets), for example, the electrical signals obtained from the received laser reflection light and welding light become weak. On that account, determination accuracy of poor welding may decrease. Particularly, in the depressed weld in which a bead is depressed in the laser beam welding, those changes of the electrical signals which are caused due to poor welding decrease. This may cause such a case where poor welding in the workpieces cannot be detected minutely. Further, it is known that vapor light caused due to melting and evaporation of the workpieces and thermal radiation light emitted from a molten pool of the workpieces change according to a workpiece temperature, and the electrical signals obtained from the received laser reflection light and the welding light and the threshold to determine the quality of the laser beam welding change according to the workpiece temperature. Because of this, in a case where the workpiece temperature largely fluctuates in the laser beam welding, the determination accuracy of the poor welding of the workpieces may further decreases.

SUMMARY OF THE INVENTION

[0006] The present invention provides a welded portion inspection apparatus that is able to minutely inspect a welding state of a welded portion of workpieces in remote

welding in which welding is performed such that the workpieces are spaced from a laser torch, and an inspection method thereof.

[0007] A first aspect of the invention relates to a welded portion inspection apparatus that inspects a welding state of a welded portion formed at the time when a plurality of workpieces is welded. The welded portion inspection apparatus includes: a radiation portion that radiates a welding laser beam along a welding locus set in the workpieces so as to weld the workpieces, or radiates an inspection laser beam along a scanning locus set in a molten pool of the workpieces that are molten by the welding laser beam; a light-receiving portion that receives a returned light beam including at least one of reflection light of the welding laser beam or the inspection laser beam radiated by the radiation portion, the reflection light being reflected from the molten pool of the workpieces, vapor light caused due to melting and evaporation of the workpieces, and thermal radiation light emitted from the molten pool of the workpieces; and an inspection portion that inspects a welding state of a welded portion of the workpieces based on an intensity of a returned light beam received by the light-receiving portion in a first region inside the molten pool of the workpieces which is relatively close to a given point and an intensity of a returned light beam received by the light-receiving portion in a second region inside the molten pool of the workpieces which is relatively spaced from the given point.

[0008] According to the above aspect, the welding state of the welded portion of the workpieces is inspected based on the intensity of the returned light beam received in the first region inside the molten pool formed in the workpieces which is relatively close to the given point and the intensity of the returned light beam received in the second region inside the molten pool formed in the workpieces which is relatively spaced from the given point. Accordingly, in a case of remote welding in which welding is performed such that the radiation portion is spaced from the workpieces, for example, even if an electrical signal obtained from the returned light beam received by the light-receiving portion is weak or even if the intensity of the returned light beam received by the light-receiving portion changes according to a change of a workpiece temperature, it is possible to minutely inspect the welding state of the welded portion formed in the workpieces.

[0009] In the above aspect, the inspection portion may inspect the welding state of the welded portion of the workpieces based on a ratio between the intensity of the returned light beam received by the light-receiving portion in the first region and the intensity of the returned light beam received by the light-receiving portion in the second region.

[0010] According to the above aspect, the welding state of the welded portion of the workpieces is inspected based on the ratio between the intensity of the returned light beam received in the first region and the intensity of the returned light beam received in the second region. Accordingly, even if an electrical signal obtained from the returned light beam received by the light-receiving portion is weak or even if the intensity of the returned light beam received by the light-receiving portion changes according to a change of a workpiece temperature, for example, it is possible to determine the welding state of the welded portion formed in the workpieces, based on substantially uniform criteria, thereby making it possible to more minutely inspect the welding state of the welded portion of the workpieces.

[0011] In the above aspect, the inspection portion may inspect the welding state of the welded portion of the workpieces based on an average intensity of the returned light beam received by the light-receiving portion in the first region and an average intensity of the returned light beam received by the light-receiving portion in the second region.

[0012] According to the above aspect, the welding state of the welded portion of the workpieces is inspected based on the average intensity of the returned light beam received in the first region and the average intensity of the returned light beam received in the second region. Accordingly, even if the intensity of the returned light beam received by the light-receiving portion changes according to a change of a workpiece temperature or periodic vibration of a liquid level of the molten pool, for example, it is possible to determine the welding state of the welded portion formed in the workpieces, based on substantially uniform criteria, thereby making it possible to further more minutely inspect the welding state of the welded portion of the workpieces.

[0013] Note that the average intensity of the returned light beam received by the

light-receiving portion in the first region is that intensity of the returned light beam per unit length, per unit area, or per unit time which is obtained by dividing a total sum of intensities of the returned light beam received by the light-receiving portion in the first region, by a length scanned by a laser beam in the first region, an area of the first region, a 5 time during which the laser beam performs scanning in the first region, or the like. Further, the average intensity of the returned light beam received by the light-receiving portion in the second region is similarly that intensity of the returned light beam per unit length, per unit area, or per unit time which is obtained by dividing a total sum of intensities of the returned light beam received by the light-receiving portion in the second 10 region, by a length scanned by a laser beam in the second region, an area of the second region, a time during which the laser beam performs scanning in the second region, or the like.

[0014] Further, a second aspect of the invention relates to a welded portion inspection method that inspects a welding state of a welded portion formed at the time 15 when a plurality of workpieces is welded. The welded portion inspection method includes radiating a welding laser beam along a welding locus set in the workpieces so as to weld the workpieces, or radiating an inspection laser beam along a scanning locus set in a molten pool of the workpieces that are molten by the welding laser beam; receiving a returned light beam including at least one of reflection light of the welding laser beam or 20 the inspection laser beam which is reflected from the molten pool of the workpieces, vapor light caused due to melting and evaporation of the workpieces, and thermal radiation light emitted from the molten pool of the workpieces; and inspecting a welding state of a welded portion of the workpieces based on an intensity of a returned light beam received in a first region inside the molten pool of the workpieces which is relatively close to a given point 25 and an intensity of a returned light beam received in a second region inside the molten pool of the workpieces which is relatively spaced from the given point.

[0015] According to the above aspect, the welding state of the welded portion of the workpieces is inspected based on the intensity of the returned light beam received in the first region inside the molten pool formed in the workpieces which is relatively close to

the given point and the intensity of the returned light beam received in the second region inside the molten pool formed in the workpieces which is relatively spaced from the given point. Accordingly, in a case of remote welding in which welding is performed such that a laser radiation portion is spaced from the workpieces, for example, even if an electrical signal obtained from the returned light beam thus received is weak or even if an intensity of the returned light beam thus received changes according to a change of a workpiece temperature, it is possible to minutely inspect a welding state of a welded portion formed in the workpieces.

[0016] As understood from the above description, the first and second aspects of 10 the invention have such a simple configuration that, at the time when a plurality of workpieces is welded, a welding state of a welded portion of the workpieces is inspected based on an intensity of a returned light beam received in the first region inside a molten pool of the workpieces which is relatively close to a given point and an intensity of a returned light beam received in the second region inside the molten pool of the workpieces 15 which is relatively spaced from the given point. Accordingly, even if an electrical signal obtained from the returned light beam is weak or even if the intensity of the returned light beam changes according to a change of a workpiece temperature, it is possible to minutely inspect the welding state of the welded portion of the workpieces.

20

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is an overall configuration diagram schematically illustrating an overall 25 configuration of Embodiment 1 of a welded portion inspection apparatus of the present invention;

FIG. 2 is a top view to describe a form of radiation of a welding laser beam from a welding radiation portion of the inspection apparatus as illustrated in FIG. 1;

FIG. 3 is a top view to describe a form of radiation of an inspection laser beam from

an inspection radiation portion of the inspection apparatus as illustrated in FIG. 1;

FIG. 4 is a view illustrating an example of an intensity of a returned light beam in time series;

FIG. 5A is a top view to describe an exemplary relationship between a molten pool, 5 and a focal point and a scanning locus of the inspection laser beam in a case where a welding state of a welded portion is normal;

FIG. 5B is a view taken along an arrow VB-VB in FIG. 5A;

FIG. 6A is a top view to describe another exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in the case 10 where the welding state of the welded portion is normal;

FIG. 6B is a view taken along an arrow VIB-VIB in FIG. 6A;

FIG. 7A is a top view to describe an exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in a case where the welding state of the welded portion is poor;

15 FIG. 7B a view taken along an arrow VIIIB-VIIB of FIG. 7A;

FIG. 8A is a top view to describe another exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in the case where the welding state of the welded portion is poor;

FIG. 8B a view taken along an arrow VIIIB-VIIIB of FIG. 8A;

20 FIG. 9 is a view illustrating exemplary ratios between average intensities of returned light beams in the case where the welding state of the welded portion is normal and in the case where the welding state of the welded portion is poor;

FIG. 10 is an overall configuration diagram schematically illustrating an overall configuration of Embodiment 2 of the welded portion inspection apparatus of the present 25 invention;

FIG. 11A is a top view enlarging and illustrating a welded portion of an inspection sample according to Example 1;

FIG. 11B is a view taken along an arrow XIB-XIB in FIG. 11A;

FIG. 11C is a view illustrating intensities of returned light beams in the inspection sample according to Example 1 in time series;

FIG. 12A is a top view enlarging and illustrating a welded portion of an inspection sample according to Example 2;

5 FIG. 12B is a view taken along an arrow XIIB-XIIB of FIG. 12A;

FIG. 12C is a view illustrating intensities of returned light beams in the inspection sample according to Example 2 in time series;

FIG. 13 is a view illustrating ratios between average intensities of returned light beams in the inspection samples according to Examples 1, 2.

10

DETAILED DESCRIPTION OF EMBODIMENTS

[0018] The following describes embodiments of a welded portion inspection apparatus and an inspection method thereof according to the present invention, with reference to the drawings.

15 **[Embodiment 1 of Welded Portion Inspection Apparatus]**

[0019] Initially described is Embodiment 1 of the welded portion inspection apparatus of the present invention with reference to FIGS. 1 to 3.

20 **[0020]** FIG. 1 is an overall configuration diagram schematically illustrating an overall configuration of Embodiment 1 of the welded portion inspection apparatus of the present invention. Further, FIG. 2 is a top view to describe a form of radiation of a welding laser beam from a welding radiation portion of the inspection apparatus as illustrated in FIG. 1, and FIG. 3 is a top view to describe a form of radiation of an inspection laser beam from an inspection radiation portion of the inspection apparatus.

25 **[0021]** An inspection apparatus 100 illustrated in FIG. 1 is mainly constituted by a welding radiation portion 1, an inspection radiation portion 5, a light-receiving portion 2, a conversion portion 3, an amplifier 4, an inspection portion 6, and a CRT (Cathode Ray Tube) 7.

[0022] In order to weld two workpieces (e.g., steel sheets) W1, W2 put on top of one another or disposed slightly spaced from each other, the welding radiation portion 1

radiates a welding laser beam (e.g., a YAG laser having a predetermined laser wavelength) L1 to the two workpieces W1, W2. More specifically, as illustrated in FIG. 2, the welding radiation portion 1 rotates a focal point F1 of the welding laser beam L1 several times along a generally round-shaped welding locus C11 having a radius R11 set in the 5 workpiece W1, so as to radiate the welding laser beam L1 several times on the welding locus C11. Subsequently, the welding radiation portion 1 moves the focal point F1 of the welding laser beam L1 inside the welding locus C11, and rotates the focal point F1 of the welding laser beam L1 several times along a generally round-shaped welding locus C12 which has a radius R12 that is smaller than the radius R11 and which is coaxial to the 10 welding locus C11, so as to radiate the welding laser beam L1 several times on the welding locus C12. By repeating such a radiation step of the welding laser beam L1, a generally round-shaped welded portion is formed in the workpieces W1, W2, thereby joining the workpieces W1, W2 by welding (also referred to as Laser Screw Welding). Note that a center C0 of the welding locus C11 or the welding locus C12 is a welding center of the 15 welded portion formed in the workpieces W1, W2.

[0023] Here, by radiation of the welding laser beam L1 from the welding radiation portion 1, a molten pool Y1 where the workpieces W1, W2 are molten is formed on right and left sides of the welding laser beam L1 and behind the welding laser beam L1 in a traveling direction of the welding laser beam L1. In Embodiment 1, since the 20 welding laser beam L1 is radiated along the generally round-shaped welding loci C1, C2 as described above, a generally round-shaped molten pool Y1 is formed in the workpieces W1, W2.

[0024] As illustrated in FIG. 1, the inspection radiation portion 5 radiates an inspection laser beam L5 to the molten pool Y1 in a molten state via an optical system 8 and the light-receiving portion 2. More specifically, as illustrated in FIG. 3, the inspection 25 radiation portion 5 rotates a focal point F5 of the inspection laser beam L5 several times at a generally constant speed along a generally round-shaped scanning locus C51 having a radius R51 set inside an outer edge of the molten pool Y1, so as to radiate the inspection laser beam L5 several times on the scanning locus C51. Subsequently, the inspection

radiation portion 5 moves the focal point F5 of the inspection laser beam L5 inside the scanning locus C51, and rotates the focal point F5 of the inspection laser beam L5 several times along a generally round-shaped scanning locus C52 which has a radius R52 that is smaller than the radius R51 and which is coaxial to the scanning locus C51, so as to radiate 5 the inspection laser beam L5 several times on the scanning locus C52. By repeating such a radiation step of the inspection laser beam L5, the inspection radiation portion 5 radiates the inspection laser beam L5 to a whole of the generally round-shaped molten pool Y1 formed in the workpieces W1, W2. Note that a center of the scanning loci C51, C52 is set to a welding center C0 of the welding loci C11, C12, for example.

10 [0025] As illustrated in FIG. 1, while the inspection laser beam L5 is radiated from the inspection radiation portion 5 to the molten pool Y1, the light-receiving portion 2 receives a returned light beam L2 including reflection light of the inspection laser light L5 which is reflected from the molten pool Y1 of the workpieces W1, W2, vapor light (plasma light) caused due to melting and evaporation of the workpieces W1, W2, thermal radiation 15 light (infrared light) emitted from the molten pool Y1 of the workpieces W1, W2, and the like.

20 [0026] The conversion portion 3 converts, into an electrical signal, the returned light beam L2 received by the light-receiving portion 2 and condensed via the optical system 8 and a condenser lens 9, and outputs the electrical signal to the amplifier 4. The amplifier 4 amplifies a signal intensity of the electrical signal output from the conversion portion 3, and transmits it to the inspection portion 6.

25 [0027] The inspection portion 6 performs signal processing on the electrical signal transmitted from the amplifier 4, and inspects a welding state of the welded portion formed in the workpieces W1, W2. More specifically, the inspection portion 6 calculates an average intensity of a returned light beam L2 received by the light-receiving portion 2 in a region inside the outer edge of the molten pool Y1 which is relatively close to the welding center C0 (e.g., a locus on the scanning locus C52 and on a relatively inner side with respect to the welding center C0), and an average intensity of a returned light beam L2 received by the light-receiving portion 2 in a region inside the outer edge of the molten

pool which is relatively spaced from the welding center C0 (e.g., a locus on the scanning locus C51 and on a relatively outer side with respect to the welding center C0). Then, the inspection portion 6 inspects the welding state of the welded portion formed in the workpieces W1, W2 based on a ratio between the average intensities of the returned light beams L2. Further, the inspection portion 6 transmits, to the CRT 7, a signal processing result on the electrical signal transmitted from the amplifier 4. The CRT 7 displays the signal processing result transmitted from the inspection portion 6.

[Embodiment 1 of Welded Portion Inspection Method]

[0028] Next will be described Embodiment 1 of a welded portion inspection method of the present invention by use of the welded portion inspection apparatus 100 illustrated in FIG. 1, with reference to FIGS. 4 to 9.

[0029] FIG. 4 is a view illustrating, in time series, an example of that intensity of the returned light beam which is transmitted to the inspection portion 6 of the inspection apparatus 100 illustrated in FIG. 1. Further, FIG. 5A is a top view to describe an exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in a case where the welding state of the welded portion is normal, and FIG. 5B is a view taken along an arrow VB-VB of FIG. 5A. Further, FIG. 6A is a top view to describe another exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in the case where the welding state of the welded portion is normal, and FIG. 6B is a view taken along an arrow VIB-VIB of FIG. 6A. Further, FIG. 7A is a top view to describe an exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in a case where the welding state of the welded portion is poor, and FIG. 7B is a view taken along an arrow VIIB-VIIB of FIG. 7A. Further, FIG. 8A is a top view to describe another exemplary relationship between the molten pool, and the focal point and the scanning locus of the inspection laser beam in the case where the welding state of the welded portion is poor, and FIG. 8B is a view taken along an arrow VIIIB-VIIIB of FIG. 8A. Further, FIG. 9 is a view illustrating exemplary ratios between average intensities of returned light beams in the case where the welding state of the

welded portion is normal and in the case where the welding state of the welded portion is poor.

[0030] In terms of a case where the welding state of the welded portion is normal (a case where the workpieces W1, W2 are welded normally), the following cases are 5 compared with each other: a case where the focal point F5 of the inspection laser beam L5 is rotated several times along the generally round-shaped scanning locus C51 set in the molten pool Y1 so as to radiate the inspection laser beam L5 several times on the scanning locus C51 (see FIGS. 5A and 5B); and a case where the focal point F5 of the inspection laser beam L5 is rotated several times along the generally round-shaped scanning locus 10 10 C52 having a radius smaller than that of the scanning locus C51 so as to radiate the inspection laser beam L5 several times on the scanning locus C52 (see FIGS. 6A and 6B). In the case where the inspection laser beam L5 is radiated on the scanning locus C52, the intensity of the returned light beam L2 increases due to an increase of a workpiece 15 temperature, and the like. In view of this, as illustrated in a dotted line of FIG. 4, the intensity of the returned light beam L2 received by the light-receiving portion 2 and transmitted to the inspection portion 6 via the conversion portion 3 and the amplifier 4 is larger in the case where the inspection laser beam L5 is radiated on the scanning locus C52 subsequently to the scanning locus C51 (a zone (2) in FIG. 4), as compared with the case 20 where the inspection laser beam L5 is radiated several times on the scanning locus C51 (a zone (1) in FIG. 4).

[0031] In the meantime, in a case where the welding state of the welded portion is poor (e.g., in a case of holed weld in which the workpieces are both molten and depressed), part of or all of the inspection laser beam L5 radiated from the inspection radiation portion 5 passes through the workpiece W1 or the workpiece W2 (see FIG. 8B) depending on a 25 positional relationship between the scanning locus set in the molten pool Y1 and a poor welding portion X1, so that an increase of the workpiece temperature is restrained. In view of this, as illustrated in a continuous line of FIG. 4, in a case where the focal point F5 of the inspection laser beam L5 is rotated several times along the generally round-shaped scanning locus C51 set in the molten pool Y1 so as to radiate the inspection laser beam L5

several times on the scanning locus C51 (see FIGS. 7A and 7B) (the zone (1) in FIG. 4), the intensity of the returned light beam L2 transmitted to the inspection portion 6 is equivalent to that intensity of the returned light beam L2 which is obtained when the welding state of the welded portion is normal. On the other hand, in a case where the 5 focal point F5 of the inspection laser beam L5 is rotated several times along the generally round-shaped scanning locus C52 having a radius smaller than that of the scanning locus C51 so as to radiate the inspection laser beam L5 several times on the scanning locus C52 (see FIGS. 8A and 8B) (the zone (2) in FIG. 4), the intensity of the returned light beam L2 transmitted to the inspection portion 6 is lower than that intensity of the returned light 10 beam L2 which is obtained when the welding state of the welded portion is normal.

[0032] According to the inspection method of Embodiment 1, the intensity of the returned light beam L2 received by the light-receiving portion 2 in the zone (1) illustrated in FIG. 4 (in that region inside the molten pool Y1 which is relatively spaced from the welding center C0) and an average intensity thereof are compared by the inspection portion 15 6 with the intensity of the returned light beam L2 received by the light-receiving portion 2 in the zone (2) illustrated in FIG. 4 (in that region inside the molten pool Y1 which is relatively close to the welding center C0) and an average intensity thereof. Hereby, even if the electrical signal obtained from the returned light beam L2 is weak or even if the intensity of the returned light beam L2 changes according to a change of a workpiece 20 temperature, for example, it is possible to inspect whether or not the poor welding portion X1 exists inside the outer edge of the molten pool Y1, that is, whether or not poor welding occurs in the welded portion formed in the workpieces W1, W2. More specifically, the average intensity of the returned light beam L2 received by the light-receiving portion 2 in the zone (1) illustrated in FIG. 4 and the average intensity of the returned light beam L2 25 received by the light-receiving portion 2 in the zone (2) are calculated. Then, as illustrated in FIG. 9, a ratio (e.g., the zone (2)/the zone (1)) between both of the average intensities thus calculated is compared with a predetermined threshold. Thus, it is possible to inspect whether or not the poor welding portion X1 exists inside the outer edge of the molten pool Y1, that is, whether or not poor welding occurs in the welded portion

formed in the workpieces W1, W2.

[0033] Particularly, in Embodiment 1, the inspection laser beam L5 is radiated to the molten pool Y1 along the generally round-shaped scanning loci C51, C52. On that account, it is possible to minutely inspect whether or not a generally round-shaped poor welding portion X1 exists in vicinity to the welding center C0 in the molten pool Y1.

[0034] Further, according to Embodiment 1, the inspection laser beam L5 is radiated along the scanning loci C51, C52 set in the molten pool Y1 formed by radiation of the welding laser beam L1. Then, the welding state of the welded portion is inspected based on the intensity of the returned light beam L2 received by the light-receiving portion 10 2. Accordingly, for example, even in a case where a focal position of the welding laser beam is spaced from an occurrence position of the poor welding portion X1, it is possible to appropriately adjust a scanning condition (a scanning locus and the like) of the inspection laser beam L5. This makes it possible to minutely inspect the welding state of the welded portion formed in the workpieces.

15 [0035] Note that it is considered that a periodic fluctuation of the intensity of the returned light beam L2 in the zone (1) shown in the continuous line in FIG. 4 or in the zone (2) shown in the dotted line in FIG. 4 is caused due to periodic vibration of a liquid level of the molten pool Y1 formed in the workpieces W1, W2 by radiation of the welding laser beam L1, for example. Further, it is considered that, in the zone (2) in the continuous line 20 in FIG. 4, no periodic fluctuation occurs in the intensity of the returned light beam L2 because part of or all of the inspection laser beam L5 radiated from the inspection radiation portion 5 passes through the workpieces W1, W2.

[Embodiment 2 of Welded Portion Inspection Apparatus]

[0036] Next will be described Embodiment 2 of the welded portion inspection 25 apparatus of the present invention with reference to FIG. 10.

[0037] FIG. 10 is an overall configuration diagram schematically illustrating an overall configuration of Embodiment 2 of the welded portion inspection apparatus of the present invention. An inspection apparatus 100A of Embodiment 2 as illustrated in FIG. 10 is different from the inspection apparatus 100 of Embodiment 1 as illustrated in FIG. 1

in that a welding state of a welded portion is inspected by use of reflection light of a welding laser beam radiated from a welding radiation portion. The other configuration is generally the same as the inspection apparatus 100 of Embodiment 1. Accordingly, constituents similar to those in Embodiment 1 have the same reference signs as those in Embodiment 1 and detailed descriptions thereof are omitted.

[0038] The inspection apparatus 100A illustrated in the figure is mainly constituted by a welding radiation portion 1A, a light-receiving portion 2A, a conversion portion 3A, an amplifier 4A, an inspection portion 6A, and a CRT 7A.

[0039] In order to weld two workpieces W1, W2 put on top of one another or disposed slightly spaced from each other, the welding radiation portion 1A radiates a welding laser beam L1A to the two workpieces W1, W2 via an optical system 8A and the light-receiving portion 2A. By radiation of the welding laser beam L1A from the welding radiation portion 1A, a molten pool Y1 where the workpieces W1, W2 are molten is formed on right and left sides of the welding laser beam L1A and behind the welding laser beam L1A in a traveling direction of the welding laser beam L1A.

[0040] The light-receiving portion 2A receives a returned light beam L2A including reflection light of the welding laser light L1A radiated from the welding radiation portion 1A, the reflection light being reflected from the molten pool Y1 of the workpieces W1, W2, vapor light (plasma light) caused due to melting and evaporation of the workpieces W1, W2, thermal radiation light (infrared light) emitted from the molten pool Y1 of the workpieces W1, W2, and the like.

[0041] The conversion portion 3A converts, into an electrical signal, the returned light beam L2A received by the light-receiving portion 2A and condensed via the optical system 8A and a condenser lens 9A, and outputs the electrical signal to the amplifier 4A. The amplifier 4A amplifies a signal intensity of the electrical signal output from the conversion portion 3A, and transmits it to the inspection portion 6A.

[0042] The inspection portion 6A performs signal processing on the electrical signal transmitted from the amplifier 4A, and inspects a welding state of the welded portion formed in the workpieces W1, W2. More specifically, the inspection portion 6A

calculates an average intensity of the returned light beam L2A received by the light-receiving portion 2A in a region inside an outer edge of the molten pool Y1 which is relatively close to the welding center C0 and an average intensity of the returned light beam L2A received by the light-receiving portion 2A in a region inside the outer edge of the molten pool Y1 which is relatively spaced from the welding center C0. Then, the inspection portion 6A inspects the welding state of the welded portion formed in the workpieces W1, W2 based on a ratio between the average intensities of the returned light beams L2A. Further, the inspection portion 6A transmits, to the CRT 7A, a signal processing result on the electrical signal transmitted from the amplifier 4A. The CRT 7A displays the signal processing result transmitted from the inspection portion 6A.

[0043] In a case where the welding state of the welded portion is poor, that is, in a case where a poor welding portion X1 is formed in the molten pool Y1 (e.g., in a case of holed weld), when the welding laser beam L1A is radiated from the welding radiation portion 1A to the workpieces W1, W2, for example, part of the welding laser beam L1A passes through the workpiece W1 or the workpiece W2, or the workpieces W1, W2 are partially lacked, so that an increase of a workpiece temperature is restrained. Accordingly, similarly to Embodiment 1, that intensity of the returned light beam L2A which is transmitted to the inspection portion 6A is lower than that intensity of the returned light beam which is obtained when the welding state of the welded portion is normal.

According to Embodiment 2, the inspection portion 6A compares the average intensity of the returned light beam L2A received in that region inside the molten pool Y1 which is relatively close to the welding center C0, with the average intensity of the returned light beam L2A received in that region inside the molten pool Y1 which is relatively spaced from the welding center C0. Hereby, similarly to Embodiment 1, even if the electrical signal obtained from the returned light beam L2A is weak or even if the intensity of the returned light beam L2A changes according to a change of a workpiece temperature, for example, it is possible to inspect whether or not the poor welding portion X1 is formed inside the outer edge of the molten pool Y1, that is, whether or not poor welding occurs in the welded portion formed in the workpieces W1, W2.

[0044] Note that Embodiment 1 described above deals with an embodiment in which the center of the scanning locus of the inspection laser beam is set to the welding center of the welding locus of the welding laser beam. However, it is possible to set the center of the scanning locus of the inspection laser beam to an appropriate position in the 5 molten pool (inside the outer edge of the molten pool) formed by radiation of the welding laser beam.

[0045] Further, the embodiments described above deal with an embodiment in which the welding locus of the welding laser beam and the scanning locus of the inspection laser beam have a generally round shape. However, the welding locus of the welding 10 laser beam and the scanning locus of the inspection laser beam may have a closed loop shape such as an elliptical shape or a polygonal shape, a spiral shape, or the like. Further, in a case where a part of the welded portion in which poor welding is easy to occur is predictable, it is preferable that the welding locus of the welding laser beam and the scanning locus of the inspection laser beam be set to pass through that part. Note that in a 15 case where the welding locus of the welding laser beam has a generally round shape, the welding center is a center of the welding locus. In a case where the welding locus of the welding laser beam has a closed loop shape such as an elliptical shape or a polygonal shape, the welding center can be set to, for example, a centroid of the welding locus. In a case where the welding locus of the welding laser beam has a spiral shape, the welding center 20 can be a center of the spiral of the welding locus.

[0046] Further, the above embodiments deal with an embodiment in which the intensity of the returned light beam received in that region inside the molten pool which is relatively close to the welding center is compared with the intensity of the returned light beam received in that region inside the molten pool which is relatively spaced from the 25 welding center. However, it is possible to set reference points for comparison between the intensities of the returned light beams, to appropriate positions in the molten pool formed by radiation of the welding laser beam.

[0047] Further, the above embodiments mainly deal with an embodiment in which the average intensity of the returned light beam received in that region inside the

molten pool which is relatively close to the welding center is compared with the average intensity of the returned light beam received in that region inside the molten pool which is relatively spaced from the welding center. However, part of the intensity of the returned light beam received in that region inside the molten pool which is relatively close to the 5 welding center may be compared with part of the intensity of the returned light beam received in that region inside the molten pool which is relatively spaced from the welding center.

[0048] Further, the above embodiments deal with an embodiment in which the welding laser beam and the inspection laser beam are radiated to workpieces fixed to a 10 predetermined position. However, focal positions of the welding laser beam and the inspection laser beam may be fixed and laser beam welding may be performed on the workpieces while the workpieces are being moved appropriately. Alternatively, laser beam welding may be performed on the workpieces such that the workpieces and the focal positions of the welding laser beam and the inspection laser beam are moved relative to 15 each other.

[Experiment on Inspection Samples to Evaluate Relationship of Welding State of Welded Portion with Ratio between Average Intensities of Returned Light Beams, and Results thereof]

[0049] The inventor(s) of the present invention manufactured two types of 20 inspection samples (Examples 1, 2) having different welding states, and performed intensity measurement of returned light beams from each of the inspection samples so as to evaluate a relationship of a welding state of a welded portion with a ratio between the average intensities of the returned light beams.

<Manufacturing Method of Inspection Sample and Measurement Method of Intensity of 25 Returned Light Beam from Inspection Sample>

[0050] Initially, the following generally describes a manufacturing method of an inspection sample and a measurement method of an intensity of a returned light beam from an inspection sample. Two workpieces each made from SCGA440 having a thickness of 0.7 mm were put on top of one another, and a welding laser beam was radiated to the

workpieces along a generally round-shaped welding locus so as to form a generally round-shaped welded portion having a radius of about 2.5 mm. Subsequently, an inspection laser beam (with an output of 1000 W and at a scanning speed of 90 m/min) was radiated to go around ten times along a generally round-shaped scanning locus (with a

5 welding center being taken as its center) having a radius of about 1.7 mm so as to pass through a molten pool formed in the workpieces. Then, a focal point of the inspection laser beam was moved only by about 1.4 mm, and the inspection laser beam was radiated to go around ten times along a generally round-shaped scanning locus (with the welding center being taken as its center) having a radius of about 0.3 mm. Here, a returned light
10 beam including reflection light of the inspection laser beam which was reflected from the molten pool of the workpieces, vapor light caused by melting and evaporation of the workpieces, thermal radiation light emitted from the molten pool of the workpieces, and the like was received. The returned light beam thus received was converted into an electrical signal, and a signal intensity thereof was measured. Note that, in the returned
15 light beam, particularly a signal intensity of the thermal radiation light (infrared light) emitted from the molten pool of the workpieces was measured in this experiment.

<Results of Evaluation on Relationship of Welding State of Welded Portion with Ratio between Average Intensities of Returned Light Beams according to Inspection Sample>

[0051] FIG. 11A is a top view enlarging and illustrating a welded portion of the
20 inspection sample according to Example 1, FIG. 11B is a view taken along an arrow XIB-XIB in FIG. 11A, and FIG. 11C is a view illustrating an intensity of a returned light beam of the inspection sample according to Example 1 in time series. Further, FIG. 12A is a top view enlarging and illustrating a welded portion of the inspection sample according to Example 2, FIG. 12B is a view taken along an arrow XIIB-XIIB in FIG. 12A, and FIG.
25 FIG. 12C is a view illustrating an intensity of a returned light beam of the inspection sample according to Example 2 in time series.

[0052] As illustrated in FIGS. 11A to 11C, in the inspection sample of Example 1 (a welding state is normal), it was found that an intensity of a returned light beam in a zone R2 (about 0.58 to about 0.60 sec) in which the inspection laser beam was radiated along

the scanning locus having a radius of about 0.3 mm was relatively larger than an intensity of a returned light beam measured in a zone R1 (about 0.44 to about 0.46 sec) in which the inspection laser beam was radiated along the scanning locus having a radius of about 1.7 mm. Further, in the inspection sample of Example 1, it was found that the intensity of the 5 returned light beam measured in the zone R2 included a periodic fluctuation.

[0053] On the other hand, as illustrated in FIGS. 12A to 12C, in the inspection sample of Example 2 (holed weld in which two workpieces were both molten and depressed), it was found that an intensity of a returned light beam measured in a zone R1 (about 0.44 to about 0.46 sec) in which the inspection laser beam was radiated along the 10 scanning locus having a radius of about 1.7 mm was equivalent to an intensity of a returned light beam in a zone R2 (about 0.58 to about 0.60 sec) in which the inspection laser beam was radiated along the scanning locus having a radius of about 0.3 mm. That is, it was found that the intensity of the returned light beam measured in the zone R2 in the inspection sample of Example 2 was relatively small in comparison with the inspection 15 sample of Example 1. Further, in the inspection sample of Example 2, it was found that the intensity of the returned light beam measured in the zone R1 included a periodic fluctuation, but the intensity of the returned light beam measured in the zone R2 included little periodic fluctuation.

[0054] FIG. 13 is a view illustrating ratios between average intensities of returned 20 light beams in the inspection samples according to Examples 1, 2. Here, the ratio between average intensities of returned light beams in each of the inspection samples according to Examples 1, 2 was calculated such that an average intensity (an intensity of a returned light beam per unit time) of the returned light beam measured in the zone R2 (about 0.58 to about 0.60 sec) where the inspection laser beam was radiated along the 25 scanning locus having a radius of about 0.3 mm was divided by an average intensity (an intensity of a returned light beam per unit time) of the returned light beam measured in the zone R1 (about 0.44 to about 0.46 sec) where the inspection laser beam was radiated along the scanning locus having a radius of about 1.7 mm. Note that, in FIG. 13, ten inspection samples were formed for each of Examples 1, 2, and that ratio between the average

intensities of the returned light beams which was calculated about each inspection sample was illustrated.

[0055] As illustrated in FIG. 13, it was found that the ten inspection samples of Example 1 (the welding state is normal) had substantially the same ratio between the 5 average intensities. Further, it was found that the ten inspection samples of Example 2 (holed weld) had substantially the same ratio between the average intensities. In addition to that, it was found that the ratios between the average intensities of the returned light beams in the inspection samples of Example 1 were relatively larger than the ratios between the average intensities of the returned light beams in the inspection samples of 10 Example 2.

[0056] In this experiment, an average intensity of a returned light beam received in that region (corresponding to the zone R2) inside a molten pool which is relatively close to a welding center and an average intensity of a returned light beam received in that region (corresponding to the zone R1) inside the molten pool which is relatively spaced 15 from the welding center were calculated, and a ratio between the average intensities was compared with a predetermined threshold. From this experimental results, the following was demonstrated: according to such a simple and easy method, even if the intensity of the returned light beam received by the light-receiving portion changes according to a change of a workpiece temperature (e.g., an increase of the workpiece temperature in welding, a 20 change of the workpiece temperature due to a change of an external temperature), or even if the intensity of the returned light beam received by the light-receiving portion changes according to periodic vibration of a liquid level of the molten pool, it is possible to minutely inspect the welding state of the welded portion, including poor welding such as holed weld or one-piece depressed weld in an area in vicinity to the welding center.

[0057] Thus, the embodiments of the present invention have been described with 25 reference to the drawings, but concrete configurations of the present invention are not limited to the above embodiments. Even if there are changes of design or the like within a range that does not deviate from a gist of the present invention, they are included in the present invention.

CLAIMS

1. A welded portion inspection apparatus that inspects a welding state of a welded portion formed at the time when a plurality of workpieces is welded, the welded portion inspection apparatus comprising:

a radiation portion that radiates a welding laser beam along a welding locus set in the workpieces so as to weld the workpieces, or radiates an inspection laser beam along a scanning locus set in a molten pool of the workpieces that are molten by the welding laser beam;

a light-receiving portion that receives a returned light beam including at least one of reflection light of the welding laser beam or the inspection laser beam radiated by the radiation portion, the reflection light being reflected from the molten pool of the workpieces, vapor light caused due to melting and evaporation of the workpieces, and thermal radiation light emitted from the molten pool of the workpieces; and

an inspection portion that inspects a welding state of a welded portion of the workpieces based on an intensity of a returned light beam received by the light-receiving portion in a first region inside the molten pool of the workpieces which is relatively close to a given point and an intensity of a returned light beam received by the light-receiving portion in a second region inside the molten pool of the workpieces which is relatively spaced from the given point.

2. The welded portion inspection apparatus according to claim 1, wherein:

the inspection portion inspects the welding state of the welded portion of the workpieces based on a ratio between the intensity of the returned light beam received by the light-receiving portion in the first region and the intensity of the returned light beam received by the light-receiving portion in the second region.

3. The welded portion inspection apparatus according to claim 1 or 2, wherein:

the welding locus of the welding laser beam or the scanning locus of the inspection

laser beam has a closed loop shape or a spiral shape.

4. The welded portion inspection apparatus according to claim 3, wherein:

the welding locus of the welding laser beam or the scanning locus of the inspection laser beam has a round shape or an elliptical shape.

5. The welded portion inspection apparatus according to claim 3 or 4, wherein:

the given point is a welding center of the workpieces.

6. The welded portion inspection apparatus according to any one of claims 1 to 5, wherein:

the inspection portion inspects the welding state of the welded portion of the workpieces based on an average intensity of the returned light beam received by the light-receiving portion in the first region and an average intensity of the returned light beam received by the light-receiving portion in the second region.

7. A welded portion inspection method for inspecting a welding state of a welded portion formed at the time when a plurality of workpieces is welded, the welded portion inspection method comprising:

radiating a welding laser beam along a welding locus set in the workpieces so as to weld the workpieces, or radiating an inspection laser beam along a scanning locus set in a molten pool of the workpieces that are molten by the welding laser beam;

receiving a returned light beam including at least one of reflection light of the welding laser beam or the inspection laser beam which is reflected from the molten pool of the workpieces, vapor light caused due to melting and evaporation of the workpieces, and thermal radiation light emitted from the molten pool of the workpieces; and

inspecting a welding state of a welded portion of the workpieces based on an intensity of a returned light beam received in a first region inside the molten pool of the workpieces which is relatively close to a given point and an intensity of a returned light

beam received in a second region inside the molten pool of the workpieces which is relatively spaced from the given point.

8. The welded portion inspection method according to claim 7, wherein:

in the inspecting of the welding state, the welding state of the welded portion of the workpieces is inspected based on a ratio between the intensity of the returned light beam received in the first region and the intensity of the returned light beam received in the second region.

9. The welded portion inspection method according to claim 7 or 8, wherein:

the welding locus of the welding laser beam or the scanning locus of the inspection laser beam has a closed loop shape or a spiral shape.

10. The welded portion inspection method according to claim 9, wherein:

the welding locus of the welding laser beam or the scanning locus of the inspection laser beam has a round shape or an elliptical shape.

11. The welded portion inspection method according to claim 9 or 10, wherein:

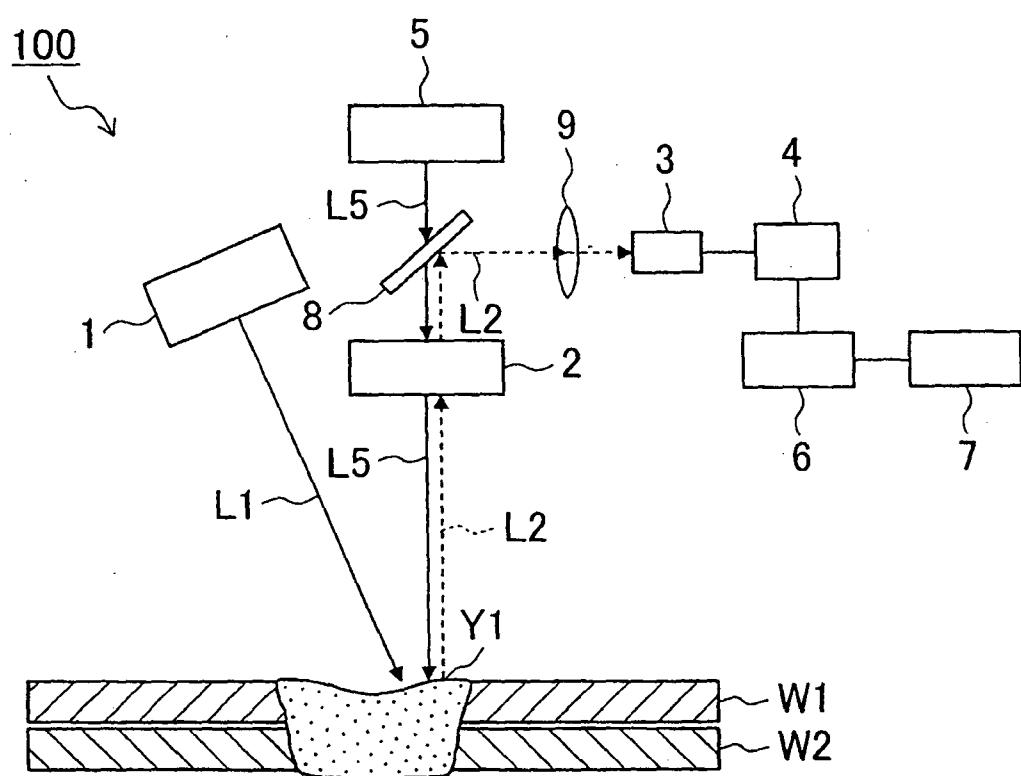
the given point is a welding center of the workpieces.

12. The welded portion inspection method according to any one of claims 7 to 11, wherein:

in the inspecting of the welding state, the welding state of the welded portion of the workpieces is inspected based on an average intensity of the returned light beam received in the first region and an average intensity of the returned light beam received in the second region.

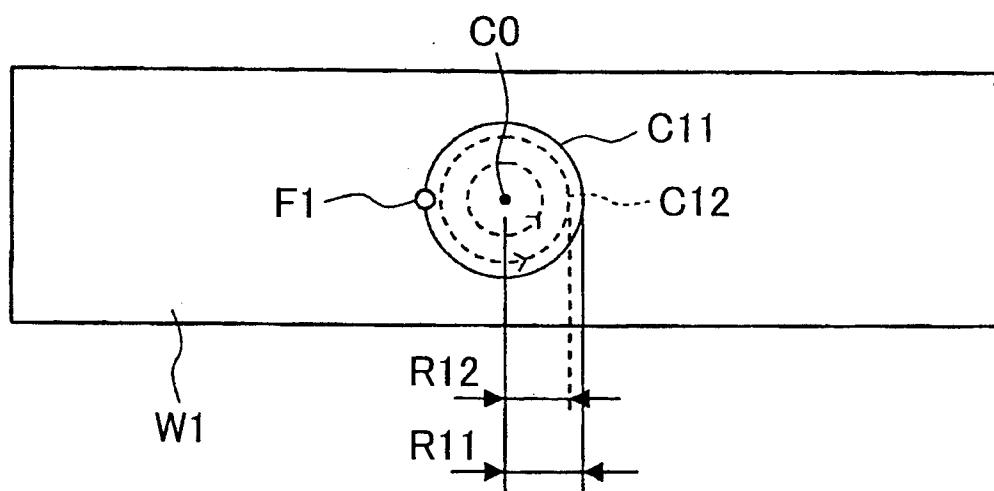
1 / 13

FIG. 1



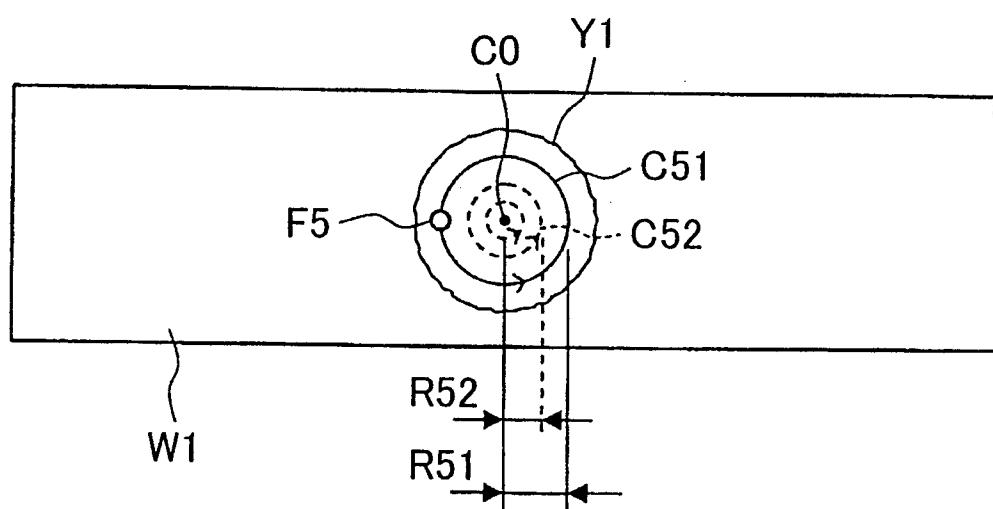
2 / 13

FIG. 2



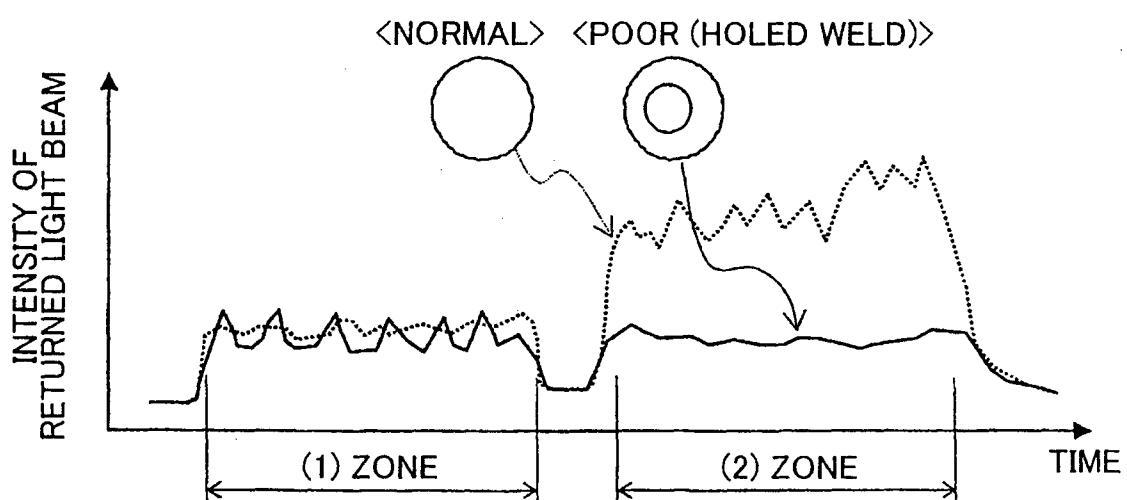
3 / 13

FIG. 3



4 / 13

FIG. 4



5 / 13

FIG. 5A

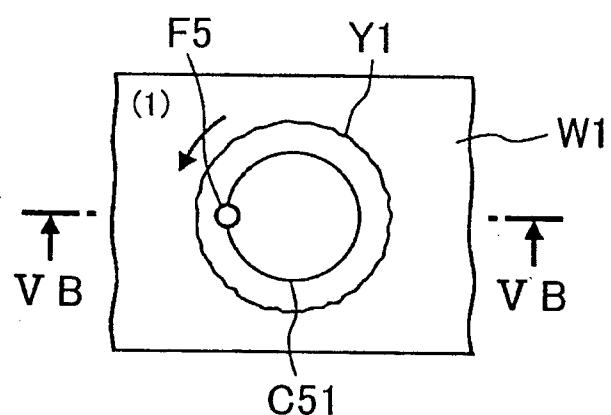
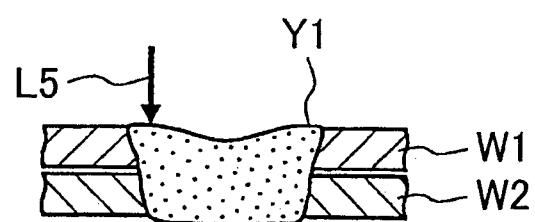


FIG. 5B



6 / 13

FIG. 6A

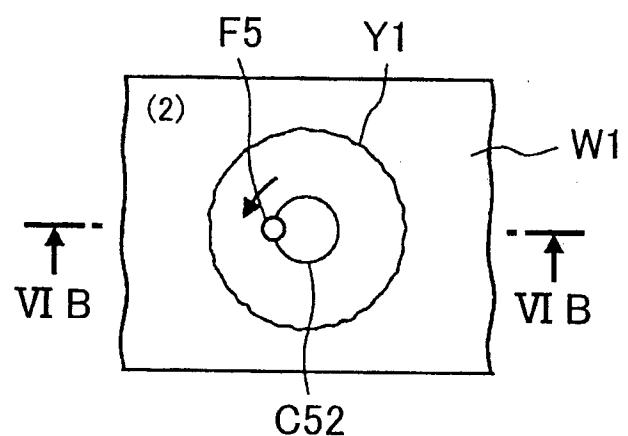
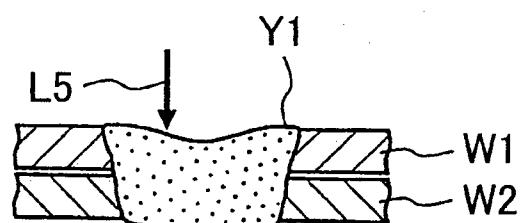


FIG. 6B



7 / 13

FIG. 7A

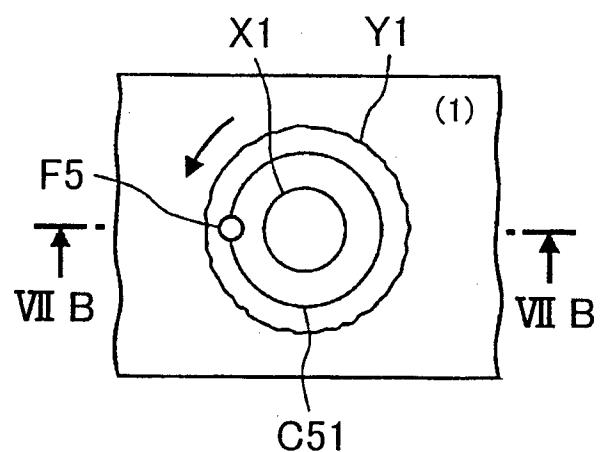
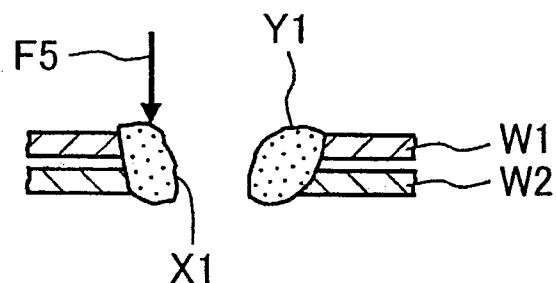


FIG. 7B



8 / 13

FIG. 8A

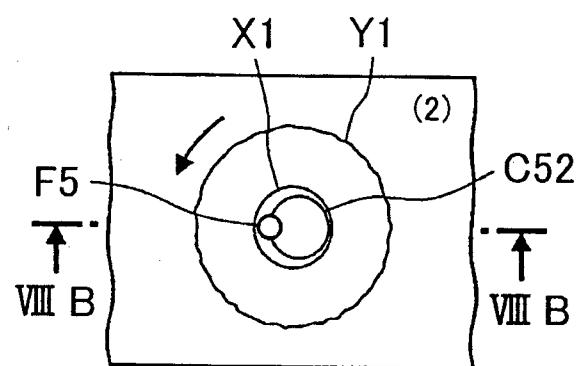
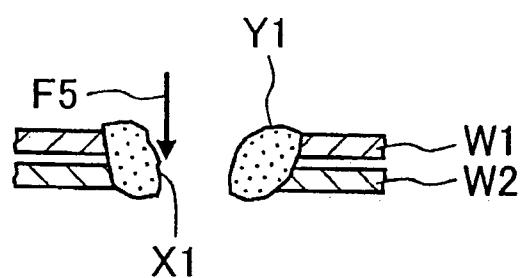


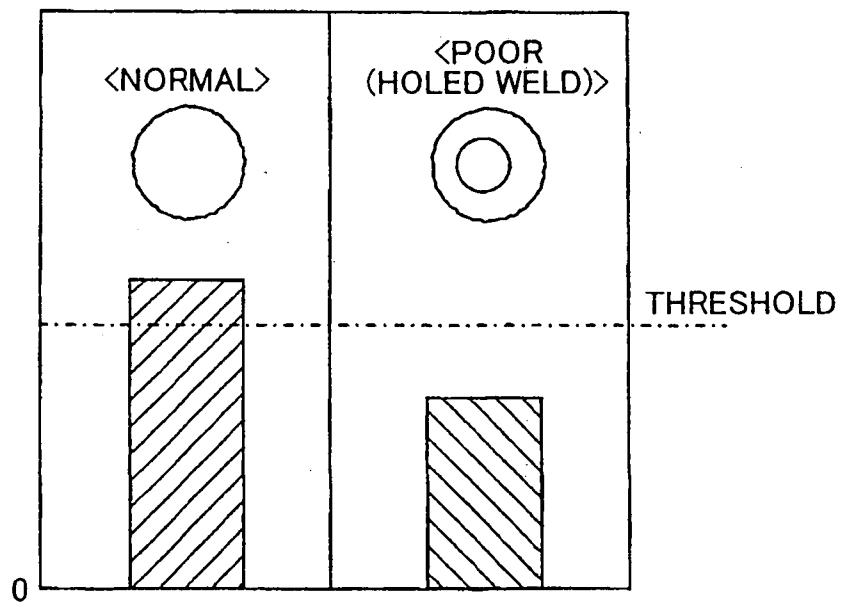
FIG. 8B



9 / 13

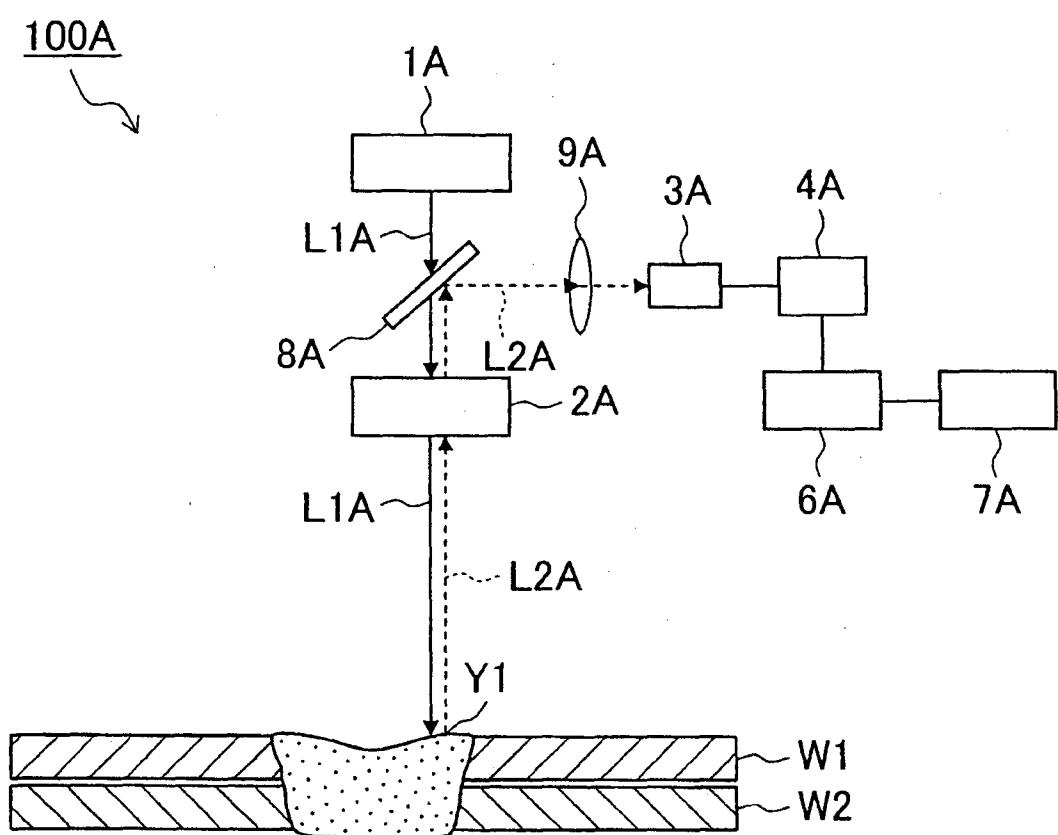
FIG. 9

RATIO BETWEEN AVERAGE INTENSITIES OF
RETURNED LIGHT BEAMS IN ZONE (1) AND ZONE (2)



10 / 13

FIG. 10



11 / 13
FIG. 11A

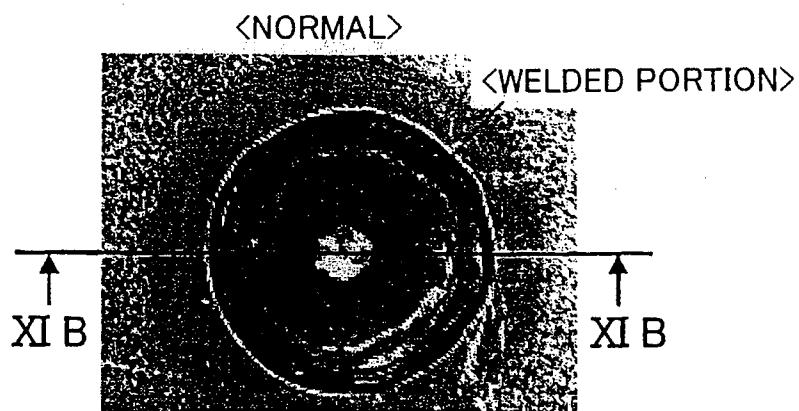


FIG. 11B

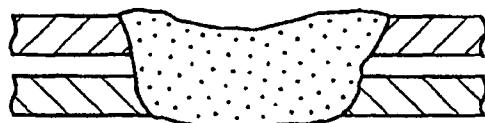
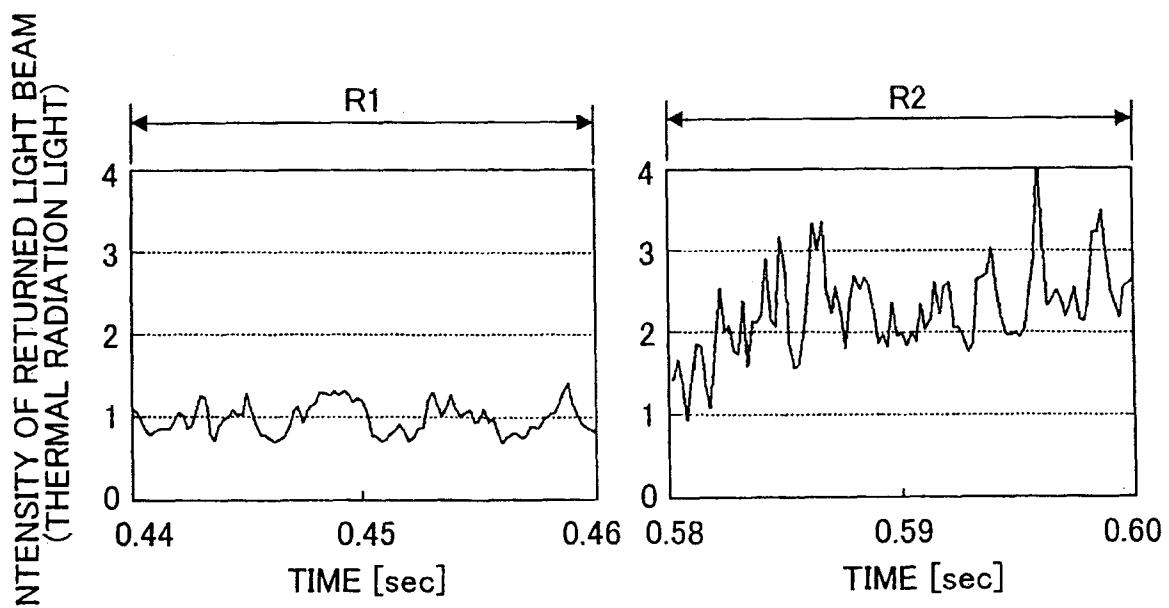


FIG. 11C



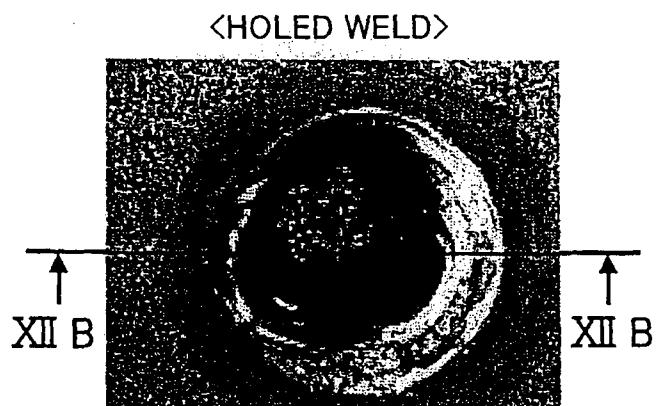
12 / 13
FIG. 12A

FIG. 12B

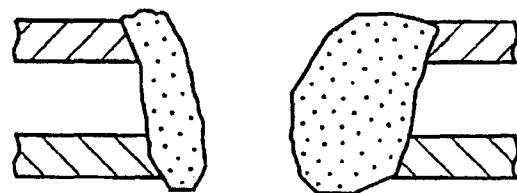
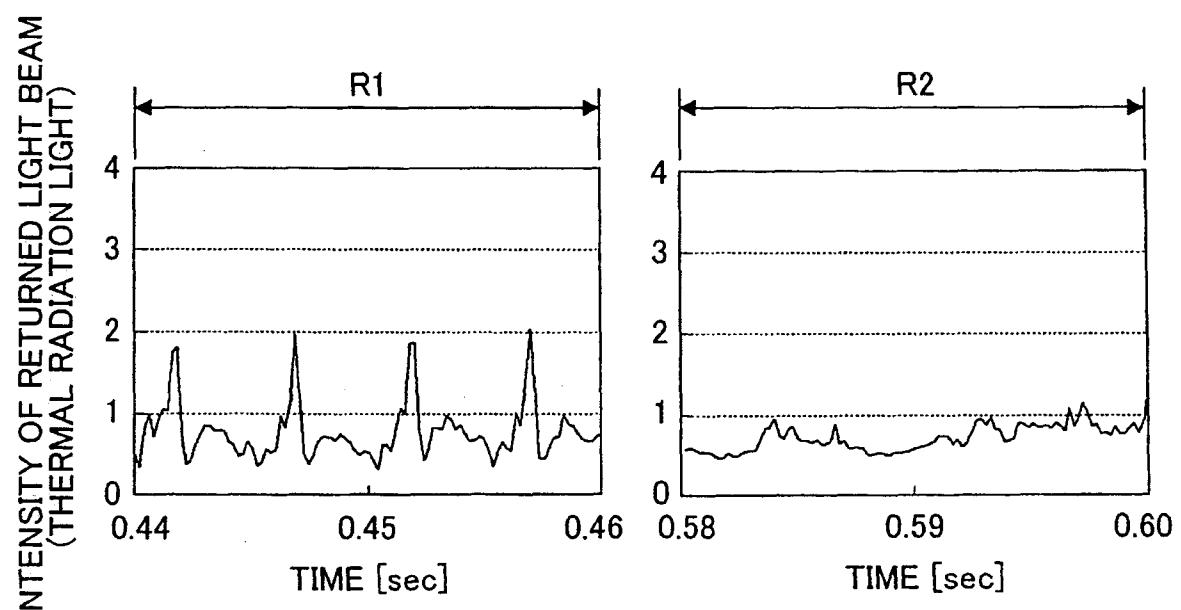


FIG. 12C



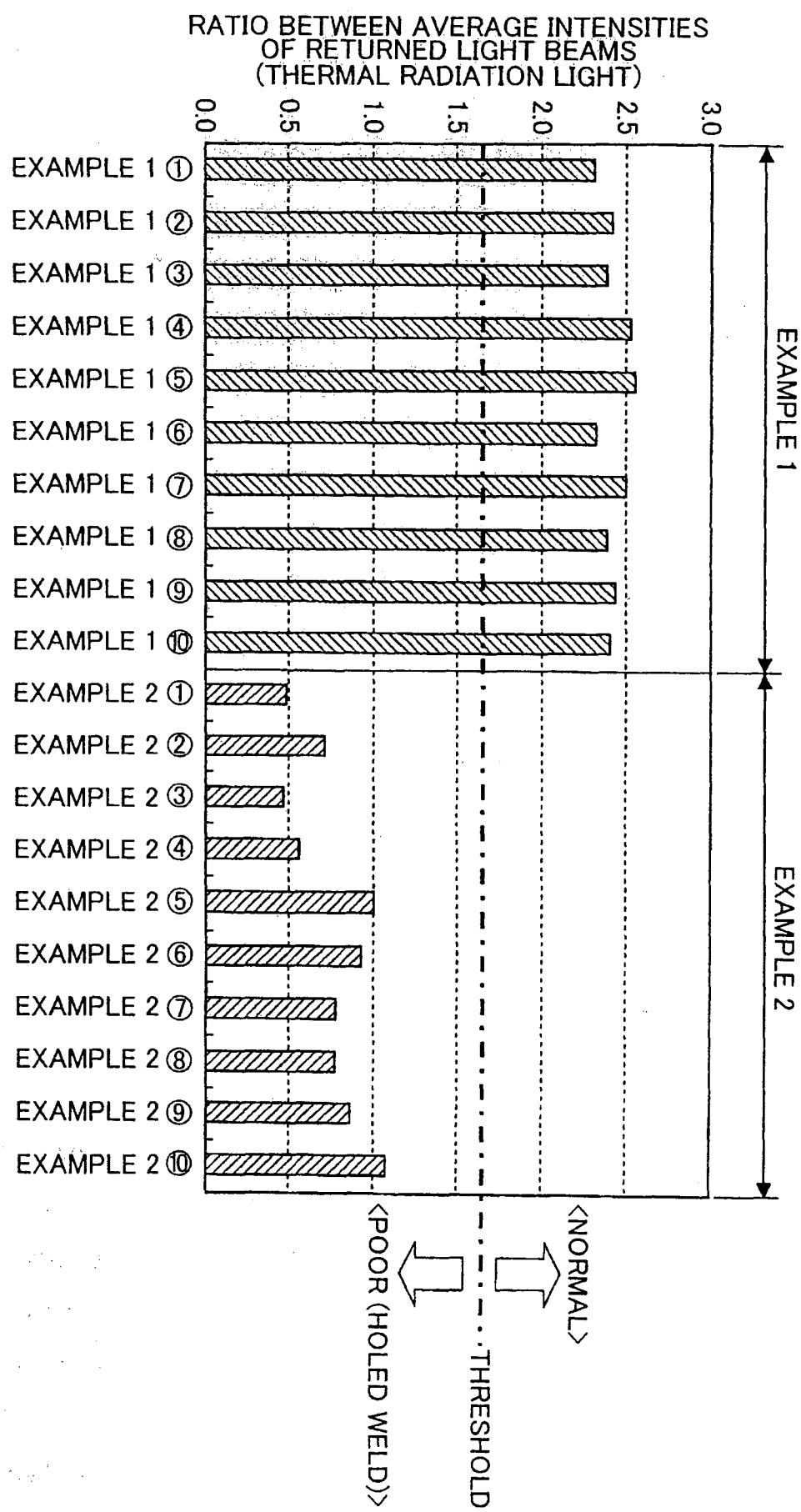


FIG. 13