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Attached open strings on a Dp-brane in the backgrounds of the pp-wave and linear dilation

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HIGHLIGHTS

- Behavior of an attached open string on a Dp-brane in the pp-wave background, accompanied by a linear dilaton, has been studied.
- Solvability of equations of motion is worked out.
- Quantization of the model is carried out.

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ABSTRACT

Open strings on a Dp-brane in the pp-wave spacetime, accompanied by a linear dilaton background, will be studied. Various properties of this system such as solvability of equations of motion and quantization will be investigated.

1. Introduction

Various backgrounds have been applied for revealing the hidden properties of the string theory. Only some of them admit solvability of the string theory. One of these backgrounds is the pp-wave metric which is supported by a constant 5-form flux [1], and can be derived from the $AdS_5 \times S^5$ manifold via its Penrose limit. The pp-wave spacetime is a maximal supersymmetric manifold in which string theory, in the light-cone gauge, is exactly solvable [1,2].

On the other hand, we have the linear dilaton field as a profitable background for the non-critical string theory [3]. This background has many prominent applications in the string theory [3,4]. For

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example, it is a trusty method for reduction of the spacetime dimension without compactification. It also significantly modifies behaviors and evolutions of the strings and D-branes and their classical solutions [5].

In this paper we shall consider both of the above backgrounds simultaneously, i.e. we shall study an open string ending on a Dp-brane in the pp-wave spacetime with the linear dilaton field. Our calculations are in the light-cone gauge, and we shall investigate the solvability of the theory. For avoiding differential equations of order more than four we apply the dilaton field only in two dimensions of the brane. Therefore, the equations completely are solvable. Due to the nature of the solutions of the worldsheet fields we have to do the quantization of the system by the symplectic method.

This paper is organized as follows. In Section 2, our setup will be fixed, and equations of motion and boundary conditions will be extracted. In Section 3, the solutions of the worldsheet fields will be given. In Section 4, the quantization of the system will be done. Section 5 is devoted to the conclusions and outlook.

2. Setup and initial equations

The pp-wave background includes a plane wave metric with a constant R–R 5-form flux

$$\begin{aligned} &ds^2 = -f^2 X^I X^I (dX^+)^2 + 2dX^+ dX^- + dX^I dX^I, \quad I = 1, 2, \ldots, 8 \\ &F_{+1234} = F_{+5678} = 2f. \end{aligned} \tag{1}$$

Now we investigate behavior of an open string, attached to a Dp-brane, in the pp-wave spacetime which is smeared by a dilaton field Φ. We use the light-cone coordinates $X^\pm = (X^9 \pm X^0)/\sqrt{2}$ with $X^+ = x^+ + 2\alpha' p^+ \tau$. Therefore, the string action in these backgrounds is given by

$$S = -\frac{1}{4\pi\alpha'} \int_\Sigma d^2\sigma \sqrt{-h} \left[h^{ab} \left(\partial_a X^I \partial_b X^I - f^2 X^I X^I \partial_a X^+ \partial_b X^+ + 2\partial_a X^+ \partial_b X^- \right) + \alpha' \Phi \, R^{(2)} \right], \tag{2}$$

where the string worldsheet Σ has the metric h_{ab} with $h = \det h_{ab}$. The scalar curvature of the worldsheet $R^{(2)}$ is constructed of the metric h_{ab}.

Since an arbitrary dilaton field induces unsolvable equations, we consider a special dilaton which is a linear function of some coordinates along the brane. That is, we apply the dilaton field $\Phi = a_k X^k$, where a_k represents a constant vector field parallel to the x^1x^2-plane of the brane. We supposed that dimension of the brane is $p \geq 2$ and its directions are $\{x^\alpha | \alpha = 1, 2, \ldots, p\}$. According to the diffeomorphism symmetry of the action (2) we can choose a conformally flat metric for the worldsheet, i.e. $h_{ab}(\sigma, \tau) = e^{\rho(\sigma,\tau)}\eta_{ab}$ with $\eta_{ab} = \text{diag}(-1, 1)$. Presence of the dilaton field removes the Weyl invariance, hence the scalar field $\rho(\sigma, \tau)$ is nonzero, and will be specified by the equations of motion. Adding all these together the string action, ending on the Dp-brane, takes the form

$$S = -\frac{1}{4\pi\alpha'} \int_\Sigma d^2\sigma \left(\eta^{ab} \partial_a X^I \partial_b X^I + \mu^2 X^I X^I - 4\alpha' p^+ \partial_\tau X^- + \alpha' a_k X^k (\partial_\tau^2 - \partial_\sigma^2)\rho \right), \tag{3}$$

where the mass parameter is $\mu = 2\alpha' p^+ f$, and for obtaining the last term we used the identity $\sqrt{-h}R^{(2)} = (\partial_\tau^2 - \partial_\sigma^2)\rho$.

In fact, we should say that for the non-critical string theory the kinetic term of the scalar ρ, which is one loop quantum effect and is proportional to $\alpha' \rho \Box \rho$, should be added to the integrand of the action (3), while for the critical string theory this term is absent. Thus, for the non-critical dimensions interpretation of the sigma model is not clear.

Vanishing of variation of the action exhibits equations of motion for the fields X^Is and ρ,

$$(\Box - \mu^2) X^{I'} = 0, \quad I' \in \{3, 4, \ldots, 8\}, \tag{4}$$

$$(\Box - \mu^2) X^k + \frac{1}{2}\alpha' a^k \Box \rho = 0, \quad k \in \{1, 2\}, \tag{5}$$

$$a_k \Box X^k = 0, \tag{6}$$