Dynamic behavior of a flexible catenary riser excited by severe slugging with periodically fluctuating flow characteristics

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ABSTRACT

We experimentally investigated the flow characteristics of severe slugging (SS) in a flexible catenary riser and the excited vibration response. The severe slugging possesses three stages in one cycle namely: slug formation (SF), slug production (SP) and fast liquid production stages (FLP). The dynamic behavior varies with the flow stage, presenting spatial-temporal differences. The correlation between the responses in the two directions of the curvature plane also exhibits the spatial variation.

KEY WORDS: severe slugging, flexible catenary riser, flow-induced vibration, flow characteristics, response correlation.

INTRODUCTION

Oil and gas resources extracted from marine reserves are lifted by pipeline-riser system to floating platforms in offshore engineering. Variable gas-liquid flow regimes are formed in the riser, depending on the flow rate and gas-to-liquid ratio. Among them, severe slugging is a destructive one owing to the frequent alteration of mass distribution and the violent fluctuation of pressure, leading to the dynamic response of the riser and overload of the platform separator. With the aim of the guarantee of structural integrity, it is urgently called for the understanding of severe slugging characteristics and the associated flow-induced vibration of marine risers.

Severe slugging was firstly described by Yocum (1973). Schmidt et al. (1980, 1981, 1985) experimentally and theoretically investigated the air-kerosene flow characteristics in an inclined pipeline-to-vertical riser system and firstly proposed the severe slugging I (SSI) and severe slugging II (SSII). For the first type, the length of liquid slug ranges from one to even several height of the riser. Luo et al. (2011) broadened the range of flow velocity and incline angle of the upstream pipeline to examine the related influences. Apart from SSI and SSII, another type of severe slugging, characterized by shorter aerated liquid slugs, was observed and termed as SSIII. Moreover, severe slugging was even found in the riser with a horizontal upstream pipeline. Wang and Guo (2006) and Malekzadeh et al. (2012a) experimentally demonstrated this phenomenon. Malekzadeh et al. (2012a, 2012b, 2012c) carefully described the SSI, SSII and SSIII with more detailed stages. In the transition case between two types, a dual-frequency severe slugging was observed with the higher one related to the severe slugging cycle and the lower one associated with the transition between two metastable states. Although the divided stages are different in aforementioned literature, the characteristics of severe slugging can be concluded as follows: for SSI, the length of purely liquid slug is longer than the riser height and the slug production stage occurs before gas blowout stage; for SSII, the length of liquid slug is usually shorter than the riser height with liquid slightly aerated; the length of liquid slug becomes much shorter for SSIII, containing more gas bubbles.

As submarine risers are usually deployed in catenary configuration, Wordsworth et al. (1998) experimentally investigated the behavior of severe slugging in an inclined pipeline-to-catenary riser system. SSI was found to be similar as that in vertical riser. In contrast, gas intermittently penetrated into the riser when SSII emerged. For SSIII, gas penetration occurs continuously at the riser base. Balino et al. (2010, 2013) and Ehinmwowo et al. (2016) validated these findings theoretically.

The afore-stated literature focused on the flow characteristics. Nevertheless, the rapid modification of mass distribution and violent fluctuation of pressure along the riser may excite the dynamic response. Wang et al. (2018) and Onuoha et al. (2018) numerically investigated the severe slugging induced vibration (SSIV) of a vertical riser with an inclined upstream pipeline. It was found that the dynamic response was closely related to the severe slugging characteristics. The response amplitude was proportional to the slug velocity within a considered range. However, the constructed severe slugging perfectly reoccurred in a fixed cycle with stable flow features in their model. The associated experimental studies are scanty, to the knowledge of authors, as this complicated fluid-structure interaction issue involves in both the spatial-temporal variation of dynamic response and flow characteristics. It is the main objective to conduct this experimental work, concerning the SSIV of a flexible catenary riser as well as the variation of flow characteristics.

EXPERIMENTAL SET-UP

As shown in Fig. 1, the experimental apparatus mainly consists of a water and air supply system and a recirculation loop. The water supply system comprises of a water pump, a valve and a flowmeter in order, corresponding to the liquid flow path, while air is compressed by an air pump, stabilized by a buffer tank and then transported through a valve and a flowmeter. The flexible catenary riser made of silica gel tube was marked with 30 black rings evenly distributed along the span, and was fix-fix supported in both ends. The main parameters of the riser model are summarized in Table 1. In comparison with the flexible riser model